BBC

Science Focus
MAGAZINE
COLLECTION

VOL.16

ANSWERS TO
222
ESSENTIAL
QUESTIONS

THE ULTIMATE BOOK OF MIND-BLOWING ANSWERS

What is the Universe expanding into?

If bats are blind, why do they have eyes?

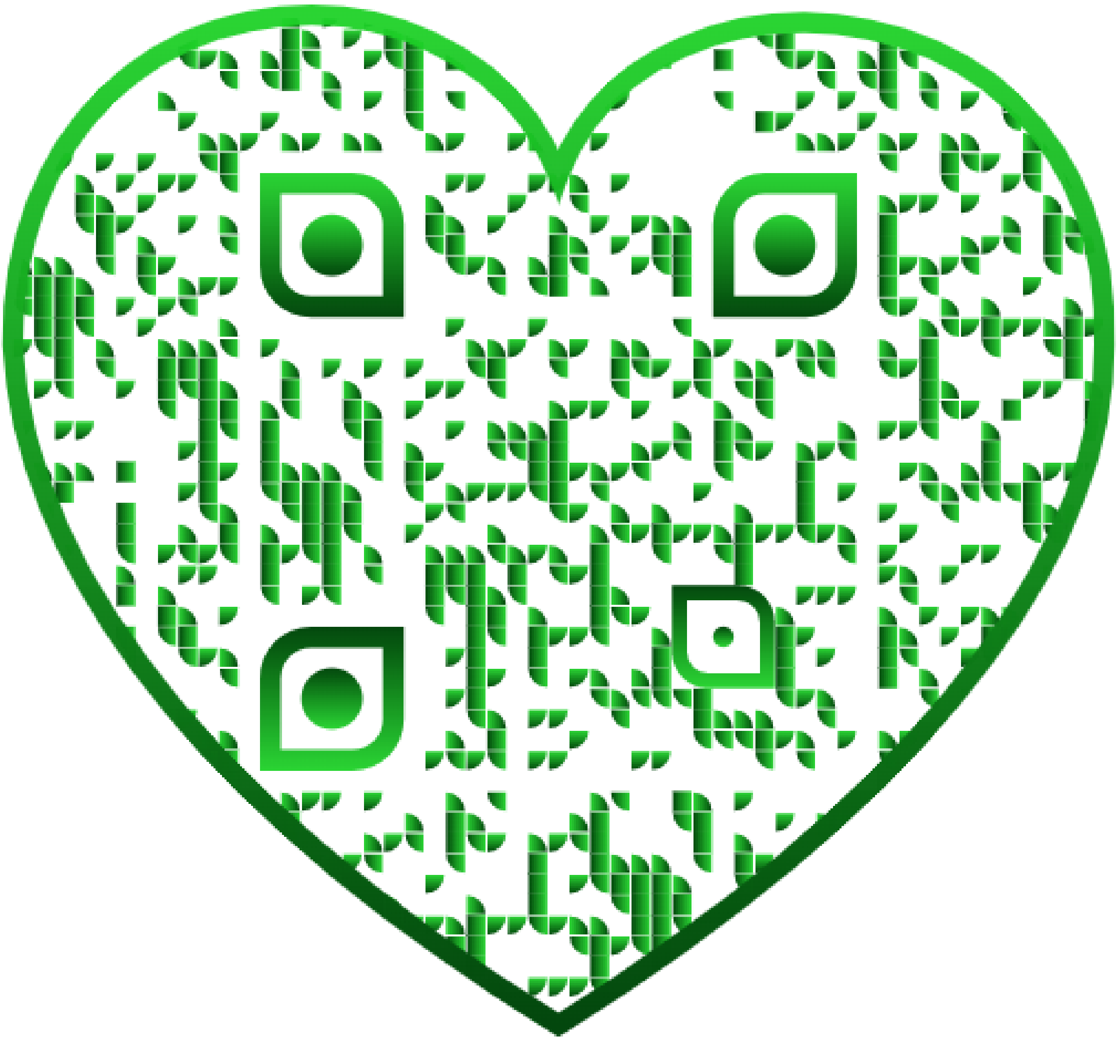
What would happen if everyone went vegan?

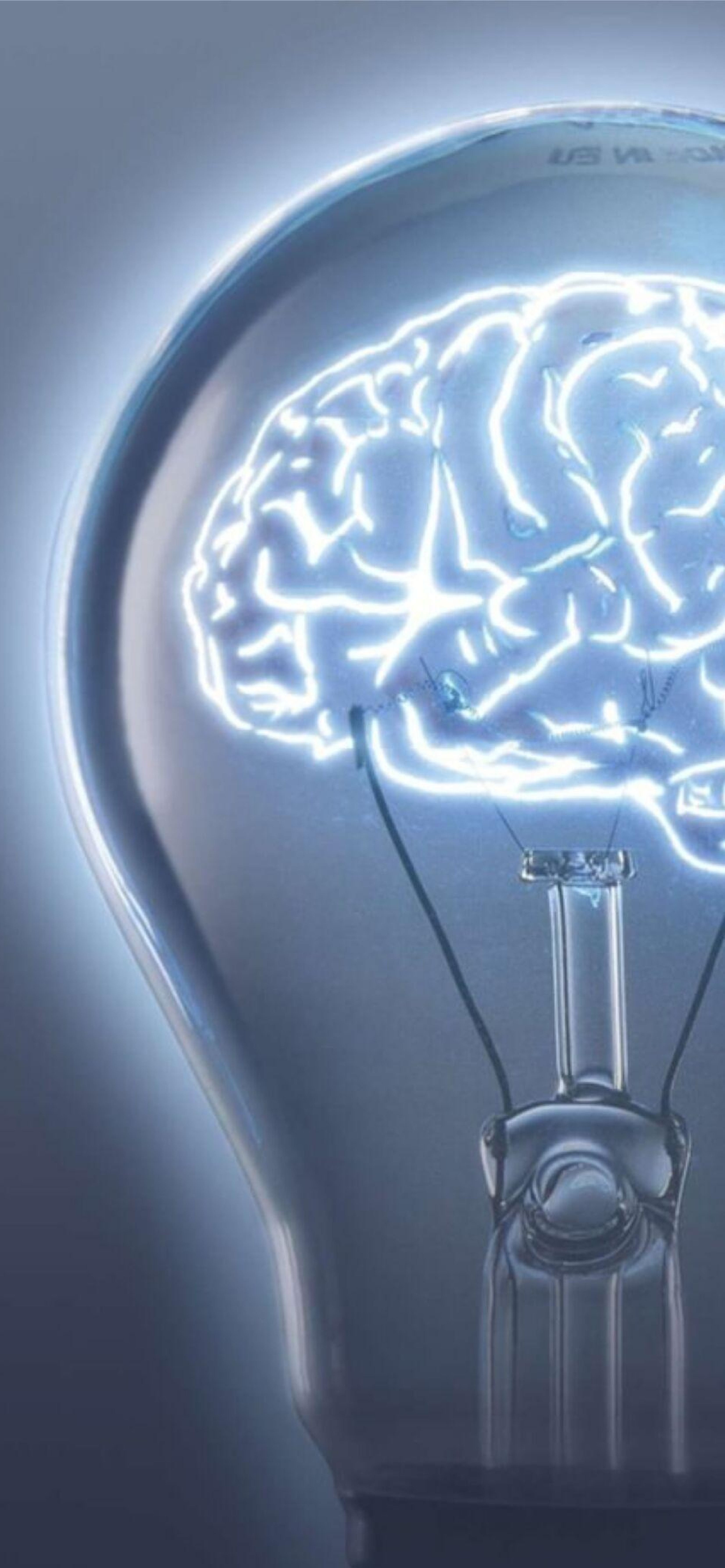
Can smart speakers eavesdrop on us?

Why did sleep evolve?

Can plants talk to each other?

What's the carbon footprint of an email?





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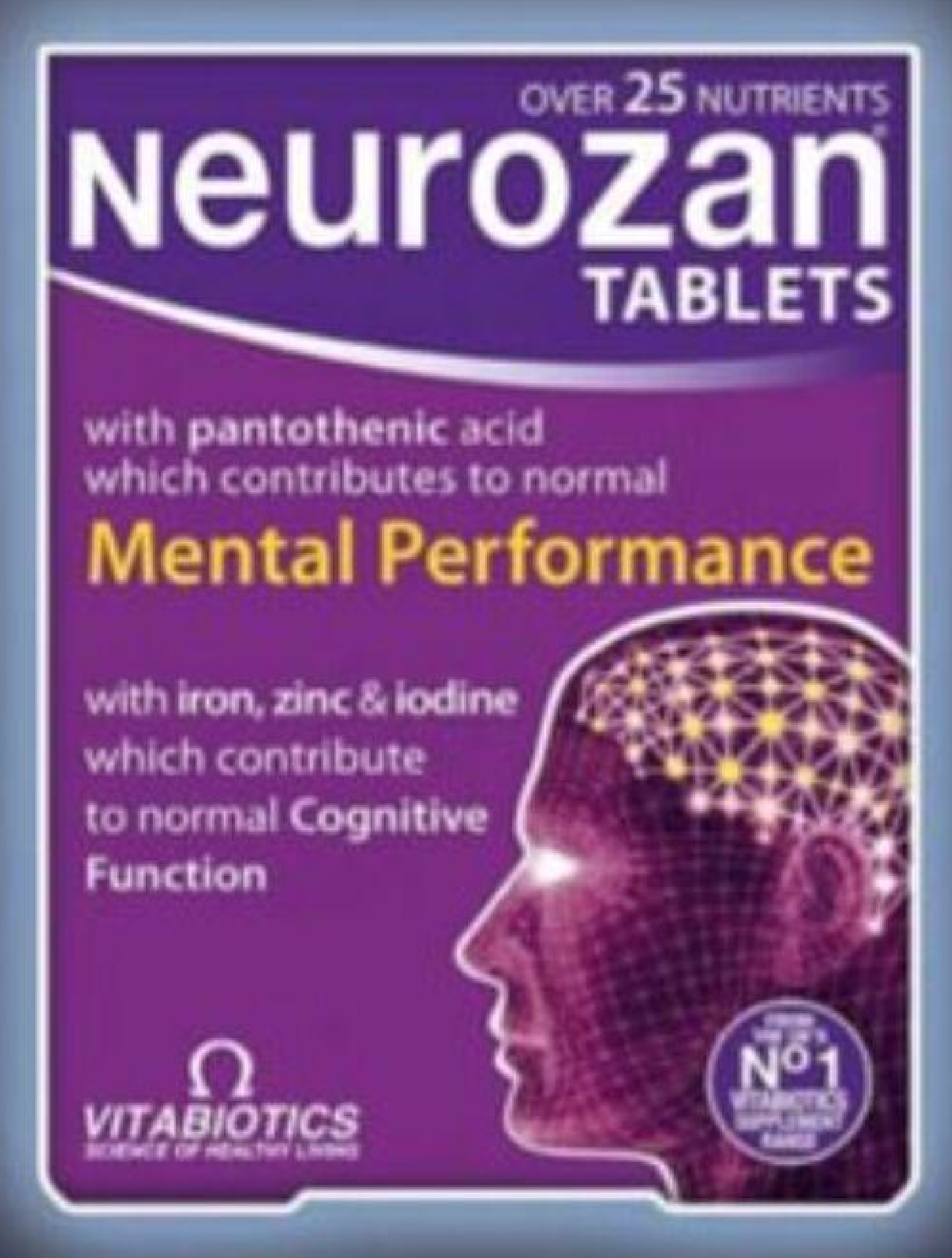
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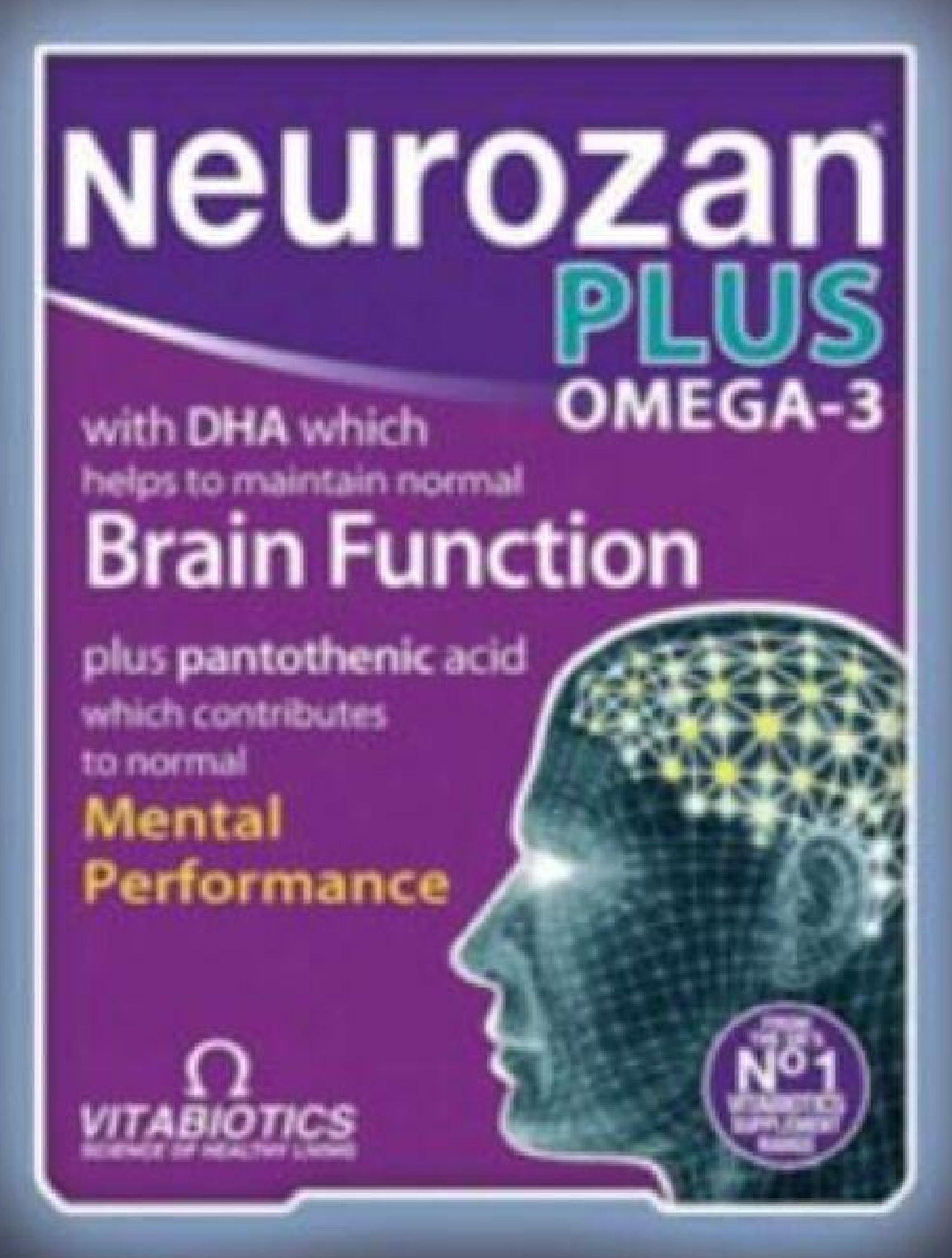
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Assume nothing

You'd be surprised at how many things each of us takes for granted. Whether you call it common sense, assumed knowledge or simply the details you don't need to think about, the sheer amount of stuff that we unquestioningly accept is staggering.

Stuff like the fact that the Earth is constantly spinning, or that some materials are magnetic, or that water is clear, or that – somewhat conveniently – there are 60 seconds in a minute and 60 minutes in an hour.

But take a moment to consider any one of those facts and questions very quickly start to arise. Questions like: why can't I feel the Earth spinning? What makes something magnetic? If water is clear, why is the sea blue? And who decided how long a second should be?

On the face of it, those all sound like simple questions. The sort of questions that we assume will have simple, straightforward answers. Which is exactly why we don't spend long thinking about what the answers might be and instead take them for granted.

Nevertheless, the questions remain. Fortunately, some people, most often scientists, are willing to seek out the answers. And, as you'll discover in this Special Edition, the answers they find are almost always astonishing. If history has taught us anything, it's that answering the simplest questions has an overwhelming tendency to lead us to mind-blowing insights about the world around us and everything in it, including ourselves.

With that in mind, we've collected over 200 questions submitted by the readers of *BBC Science Focus Magazine*, on a wide range of topics – from astronomy and physics to the natural world and the human body – and got answers to every one of them from experts in the respective fields. If you're anything like me, as you work your way through them, you'll very quickly realise what a mistake it is to ever take anything for granted.

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Daniel Bennett, Editor

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While every attempt has been made to ensure that the content of *The Ultimate Book of Mind-Blowing Answers* was as accurate as possible at time of press, we acknowledge that some information contained herein may have since become out of date. Also, the content of certain sections is occasionally subject to interpretation; in these cases, we have favoured the most respected source.

IMMEDIATE MEDIA Co

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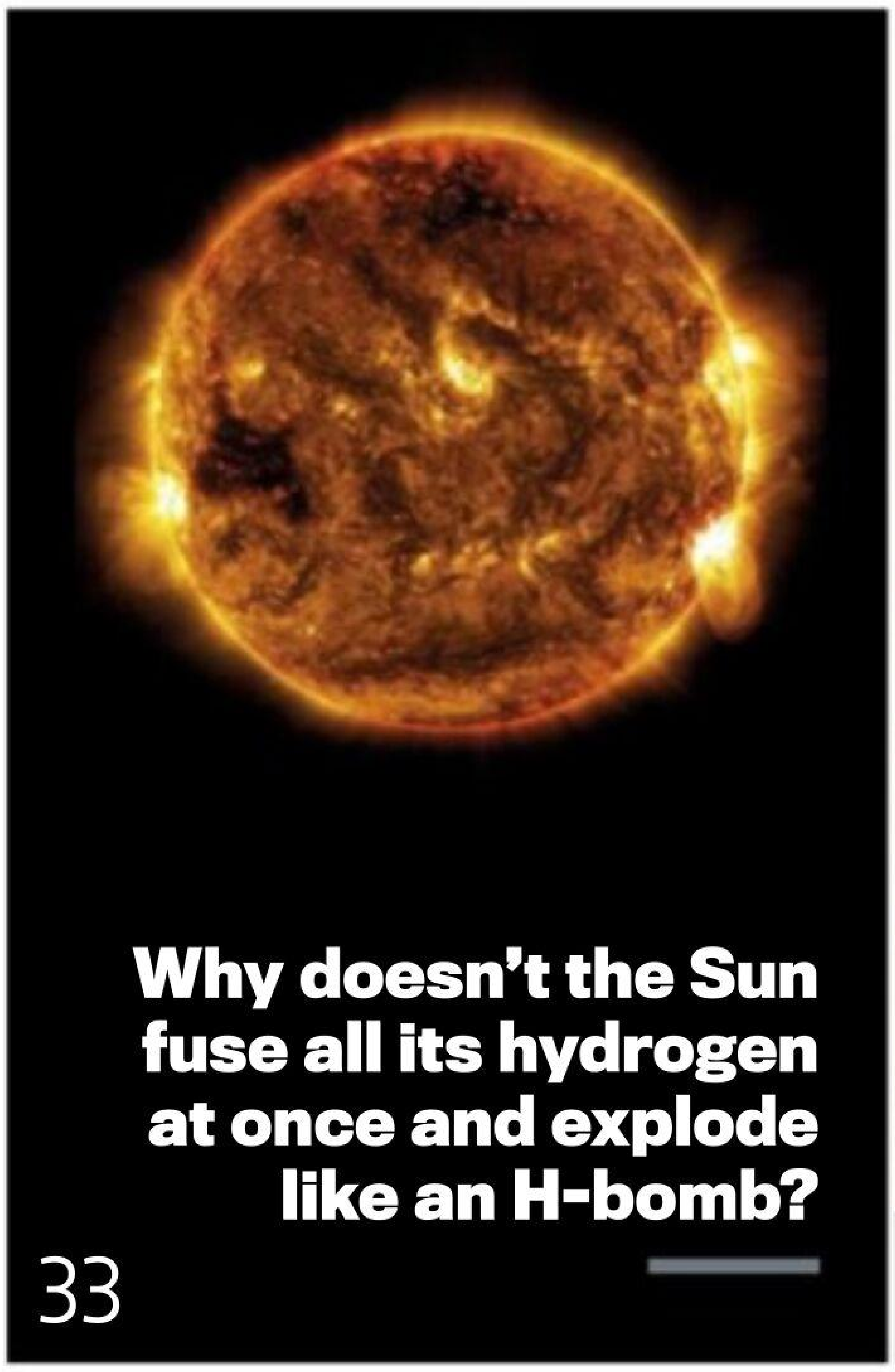

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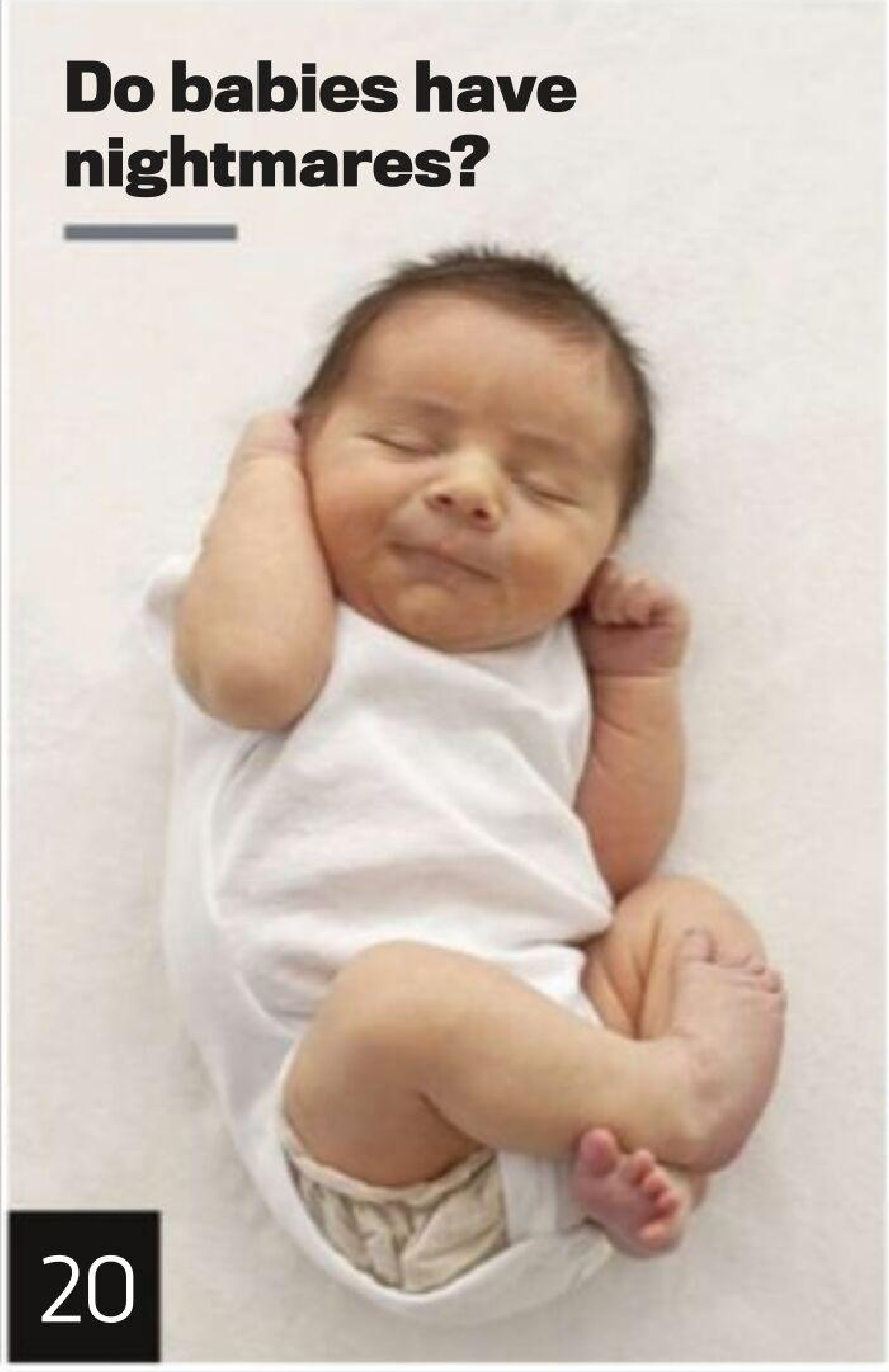

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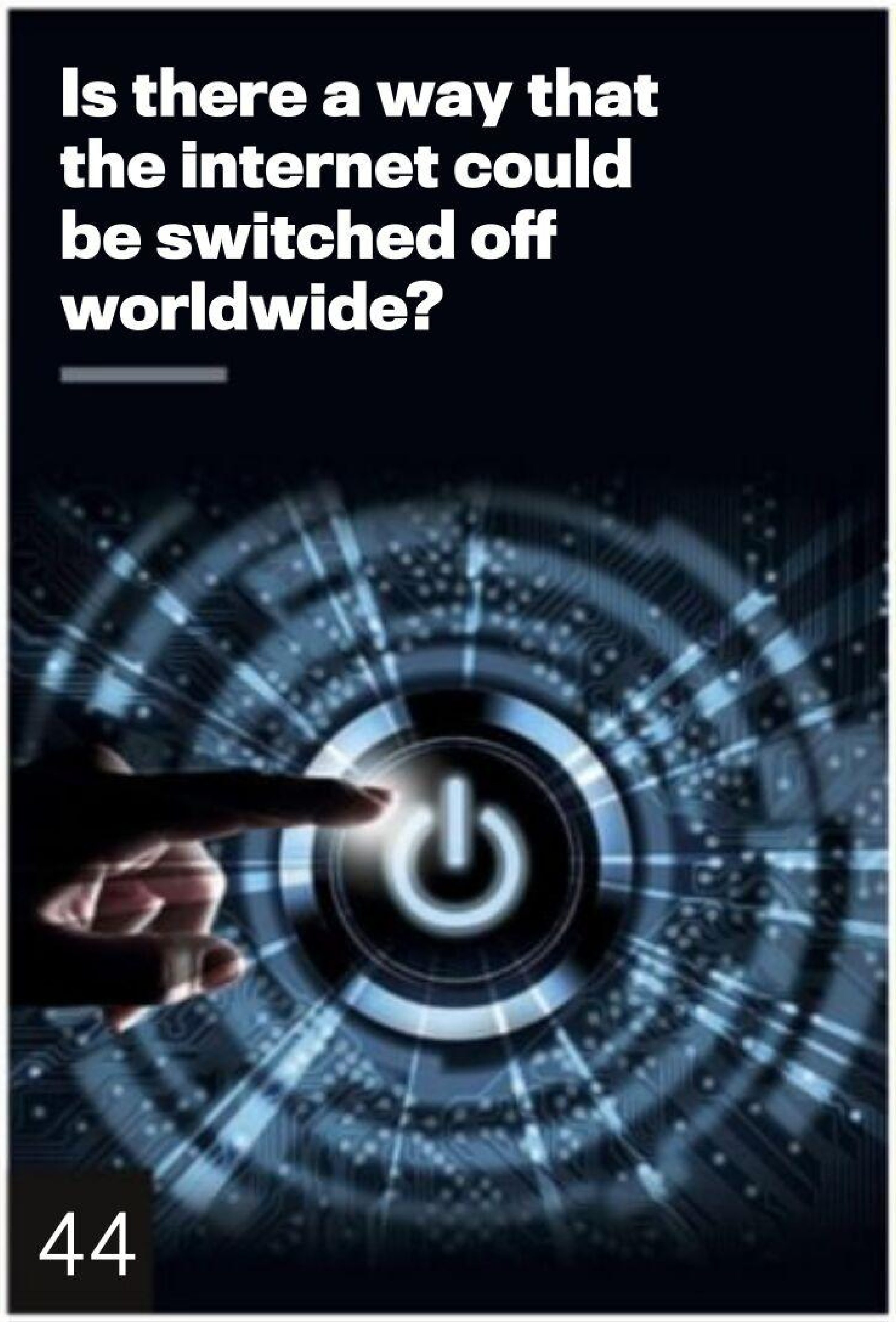

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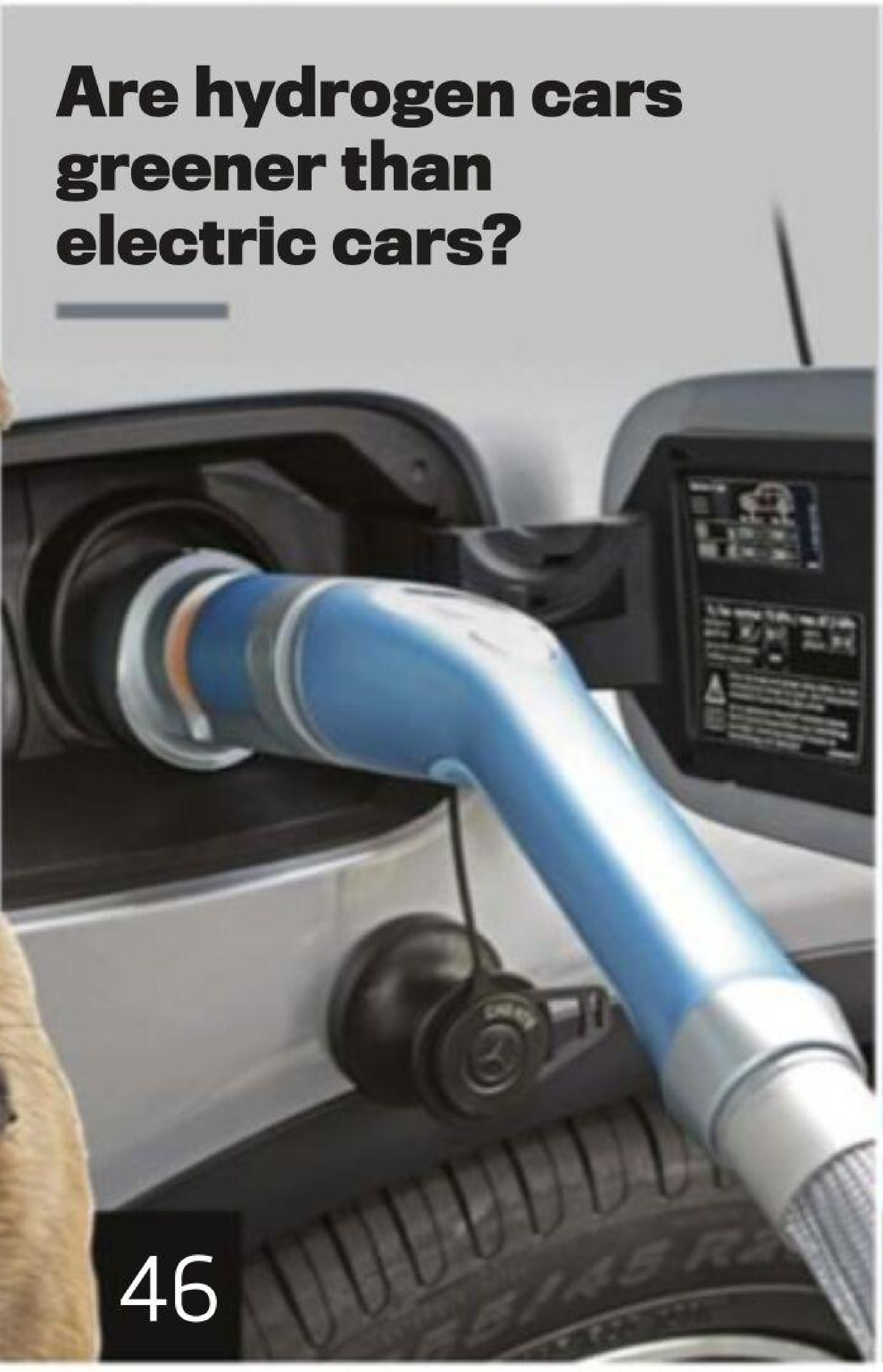

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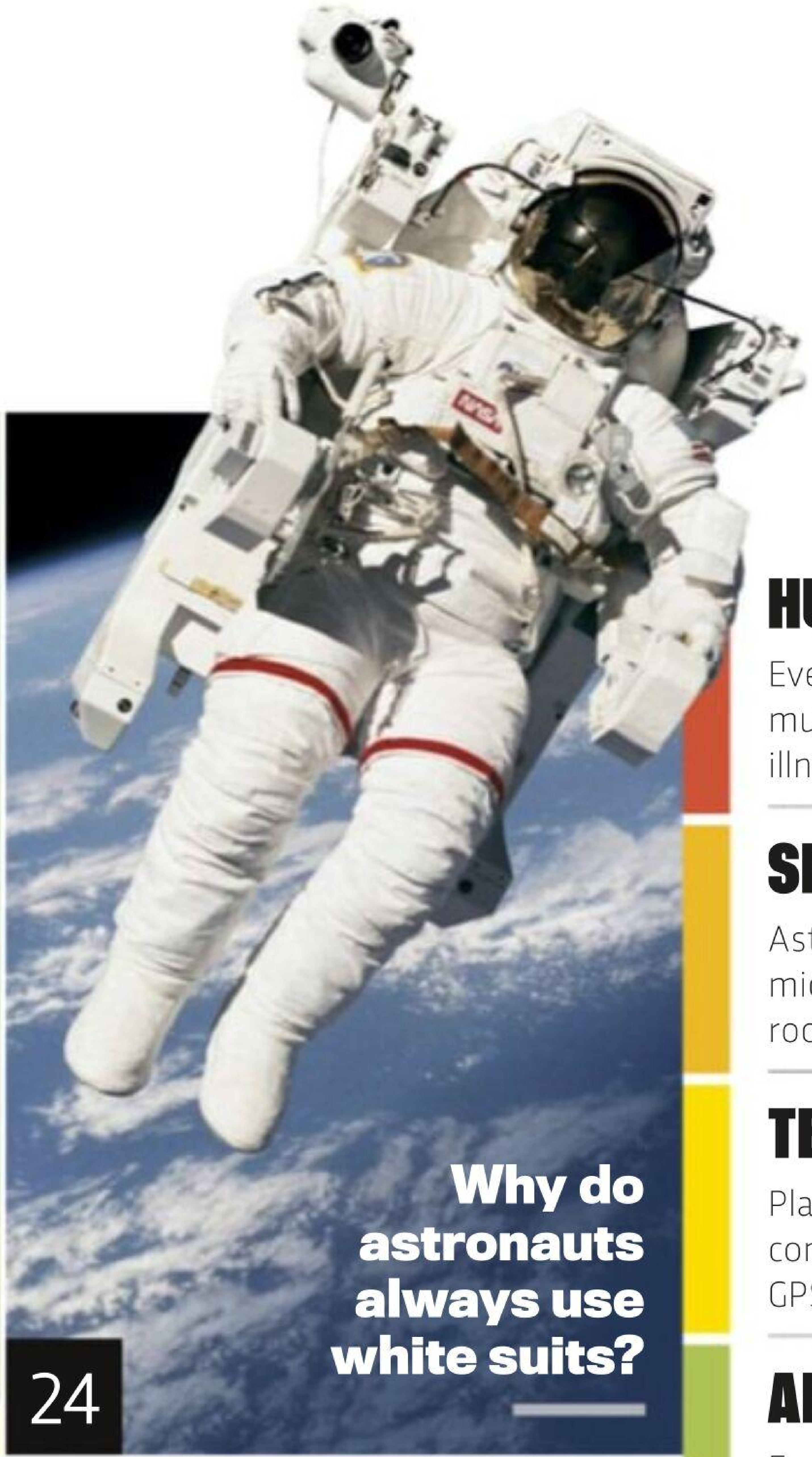

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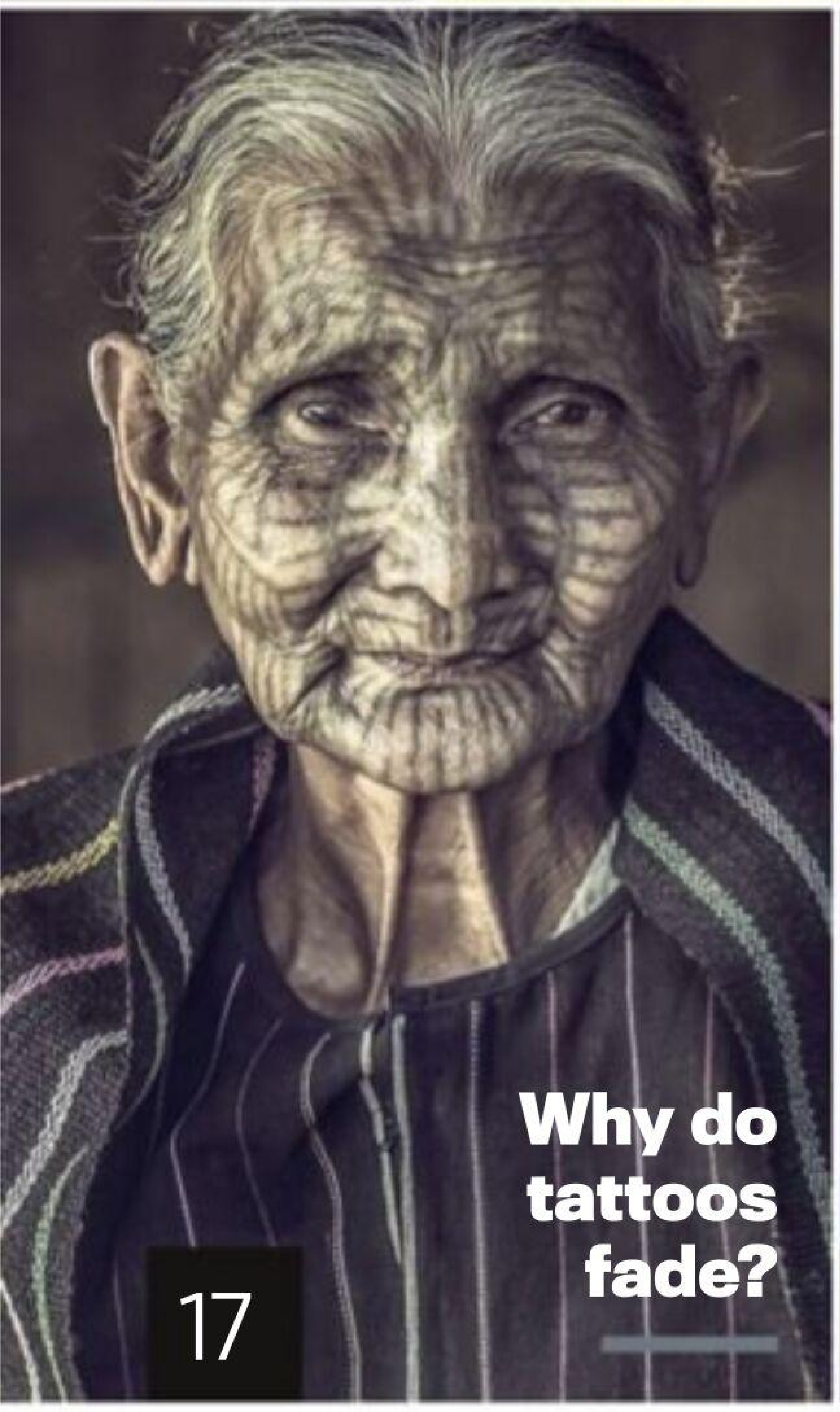

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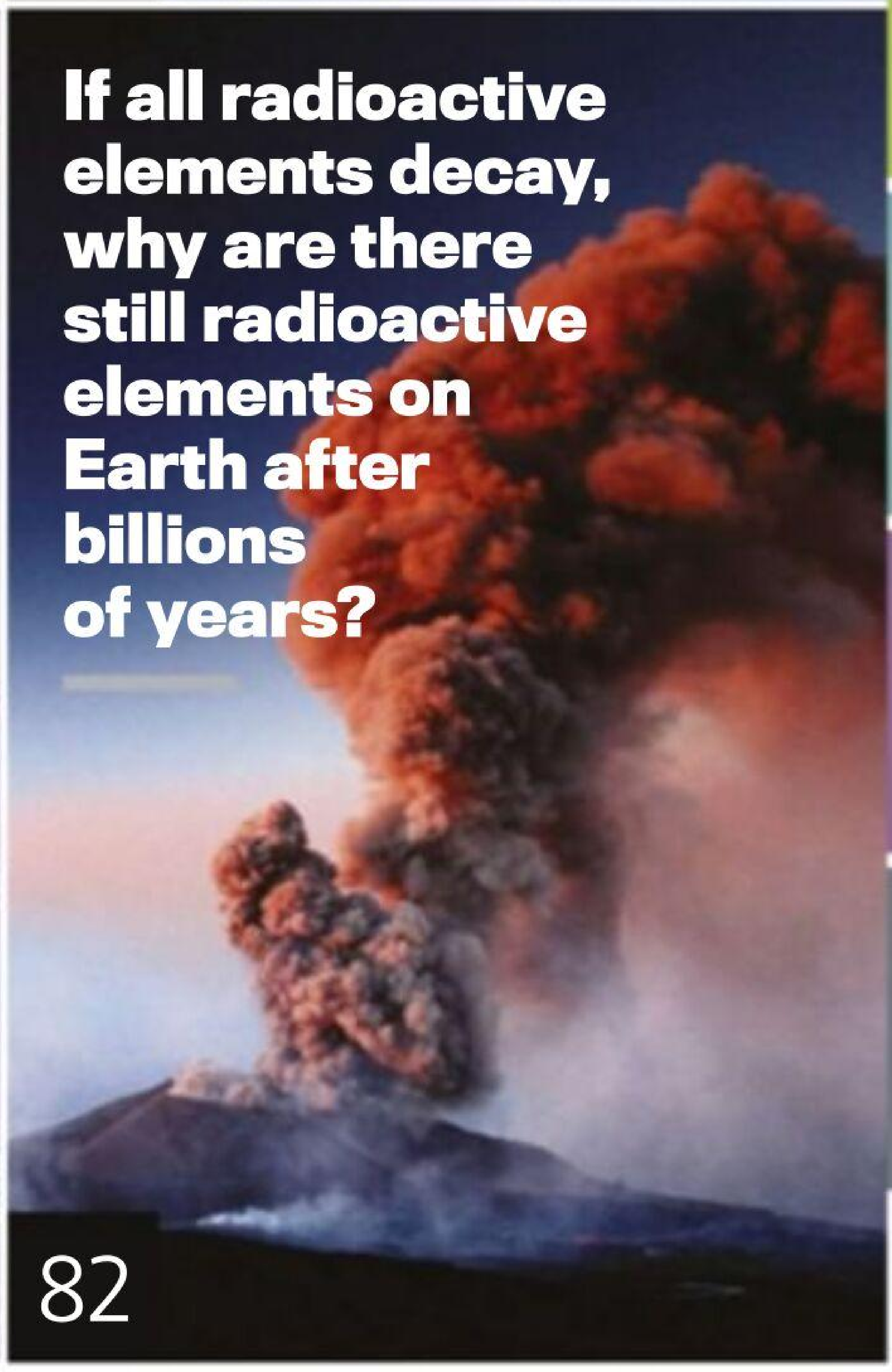

If all radioactive elements decay, why are there still radioactive elements on Earth after billions of years?

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BBC RADIO 4
Join the scientists trying to solve everyday mysteries in ***The Curious Cases of Rutherford & Fry***
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Everything you wanted to know about muscles, sweat, saliva, senses, sleep, illnesses, diet, food and memory…

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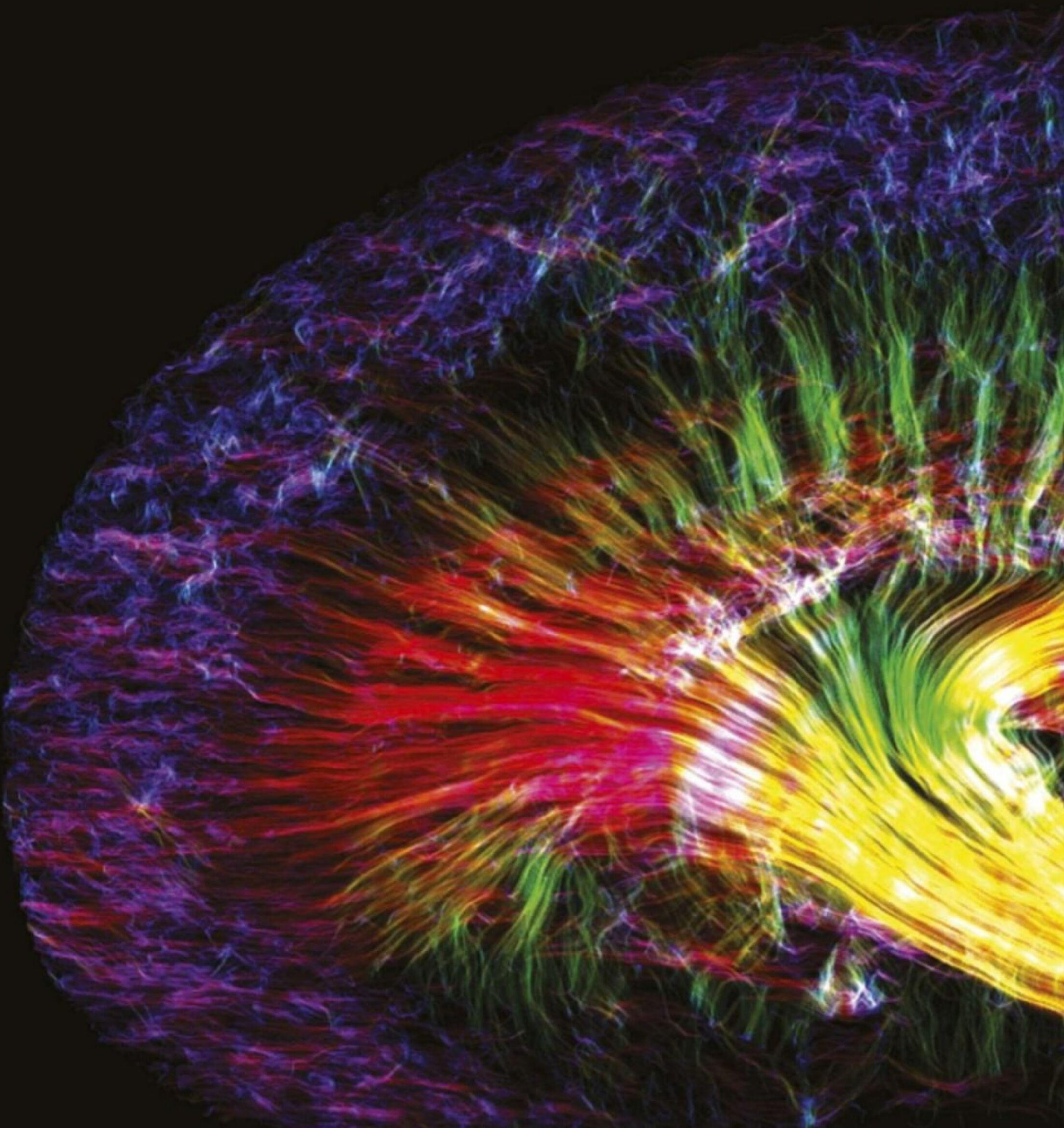

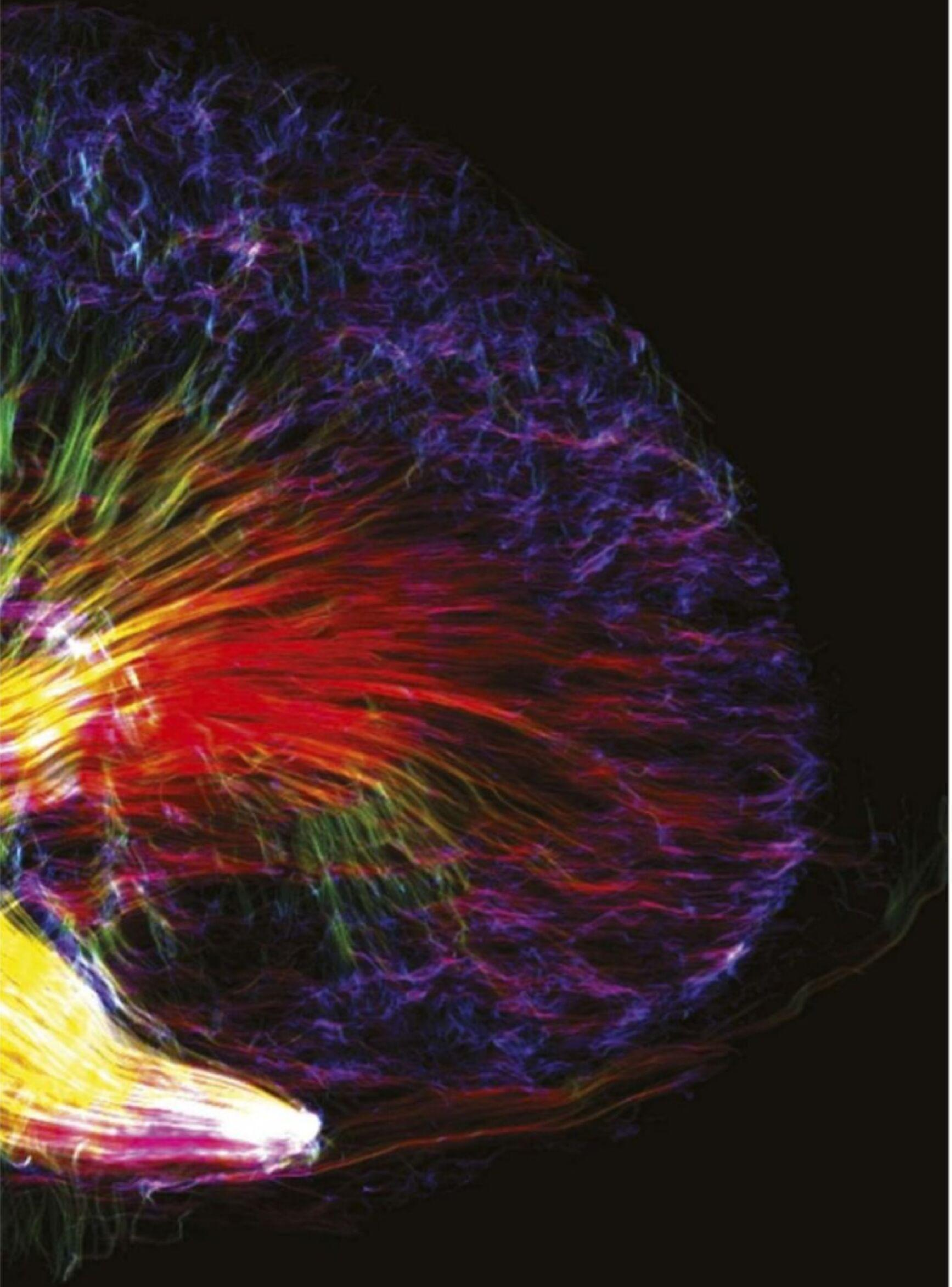

DUKE UNIVERSITY, USA

What is this?

This rainbow explosion may resemble the shape of a brain but it's actually a map of a mouse kidney, as revealed by diffusion tensor imaging (DTI) – a type of magnetic resonance imaging. DTI tracks the motions of water molecules passing through the fine tubes inside the kidney. The fluid travelling through these 'tubules' has nutrients removed and waste products added as it's turned into urine.

The colours of the fibres in this image represent their orientation, building a 3D representation of the architecture of the kidney.

This photo was the winner of 2018's BMC Research in Progress photo competition.

NIAN WANG

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IS MUSCLE MEMORY REAL?

There are two kinds, both very real. The first, properly called 'procedural memory', strengthens the synaptic pathways in your brain for specific coordinated sequences of muscle movements that you perform often. This is what allows a guitar player to form the chord shapes without consciously considering the position of each finger, for example. There is another kind of muscle memory, though. If you've previously put on muscle mass through training, then it's easier to bulk up again in the future than if you had never trained before. Muscle cells gain extra nuclei during training and these can last for 15 years, even after the muscle fibres have shrunk back to normal size. It's as if the muscles 'remember' their previous strength and find it easier to return to that level. *LV*

HUMAN BODY

MUSCLES, SWEAT, SALIVA, SENSES, SLEEP, ILLNESSES, DIET, FOOD AND MEMORY…

WHY DO WE SWEAT WHEN WE'RE ANXIOUS?

This is part of our fight-or-flight response and it happens when our sympathetic nervous system releases hormones, including adrenaline, which activates our bodies' sweat glands. Brain scans reveal that just sniffing someone else's panic-induced sweat is enough to light up regions of the brain that handle emotional and social signals. So one theory is that this sweating is an evolved behaviour that makes other people's brains more alert and primes them to be ready to deal with whatever it is that's making us anxious – handy if there's a marauding tiger on the loose. ***ED***

AM I MORE LIKELY TO GET A COLD IF I'M SHORT OF SLEEP?

There is some evidence to support this idea. In a study conducted by researchers from the US, the sleep of 164 participants was assessed over a week. Those in the study were then given some nasal drops containing rhinovirus and monitored for five days to see if they developed signs of a cold. As assessed by actigraphs (watch-like devices), those who slept for short periods (up to six hours a night) were more likely to develop a cold than those who slept for longer periods (over seven hours a night). This finding chimes well with other research showing that if we miss out on sleep for even a single night, our immune system is compromised. ***AGr***

HOW MANY FRUIT PASTILLES WOULD YOU NEED TO EAT TO GET ONE OF YOUR FIVE-A-DAY?

Rowntree's Fruit Pastilles are flavoured with the concentrated juice of seven fruits, but the amount they contain is tiny. Figures from Nestlé (Rowntree's parent company) claim that 11.5 tubes of sweets have as much vitamin C as a portion of fruit. But the five-a-day campaign isn't really about vitamins – it's about fibre and eating a varied diet. Most people in the UK aren't deficient in vitamin C, and the NHS specifically says that vitamin pills don't count as your five-a-day. Those 11.5 tubes of Fruit Pastilles have no fibre and 2,125 calories – most of which is sugar. ***LV***

No, your Fruit Pastilles habit will not lead to glowing health

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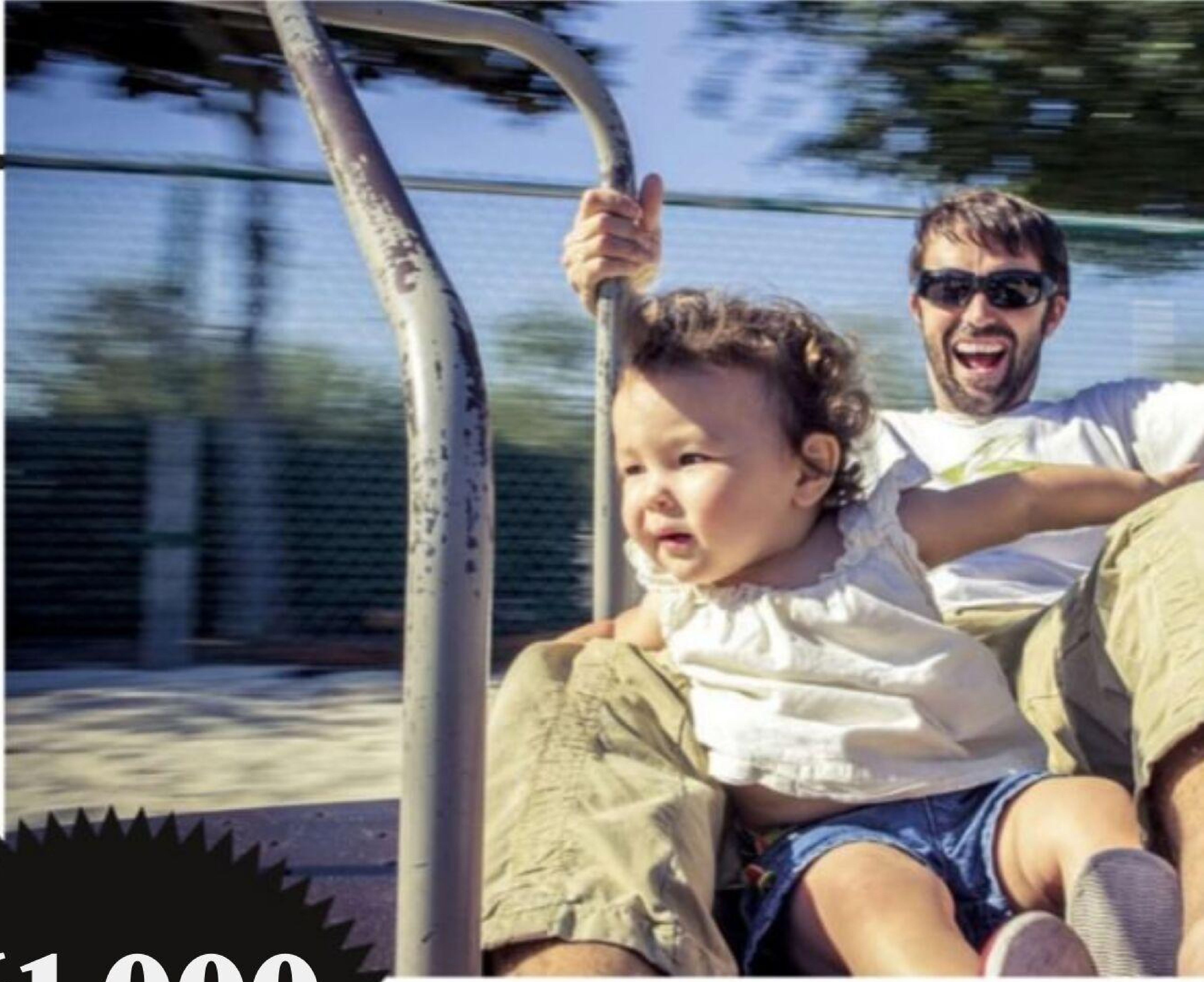


161,000

The length, in kilometres, the average adult's blood vessels would cover if they were taken out of the body and placed end to end – it's long enough to stretch around Earth's equator four times

IS THE PRACTICE OF WEARING FACE MASKS EFFECTIVE IN REDUCING THE SPREAD OF COLDS?

The wearing of face masks has become the norm in Japan, even making it as far as the couture catwalks. But what many people in the West don't realise is that they're usually worn by a person who has a cold or flu to protect others, rather than to protect the wearer. This is also true of the face masks worn by dentists and surgeons, which are designed to stop the wearer spreading their germs to the patient.

By providing a barrier, however, the masks are also effective at protecting the wearer from airborne viruses. They likely add further protection by keeping the mucous membranes in the nose and throat moist, helping our airways to expel germs, and they've also been shown to protect hay fever sufferers from pollen. *ZW*

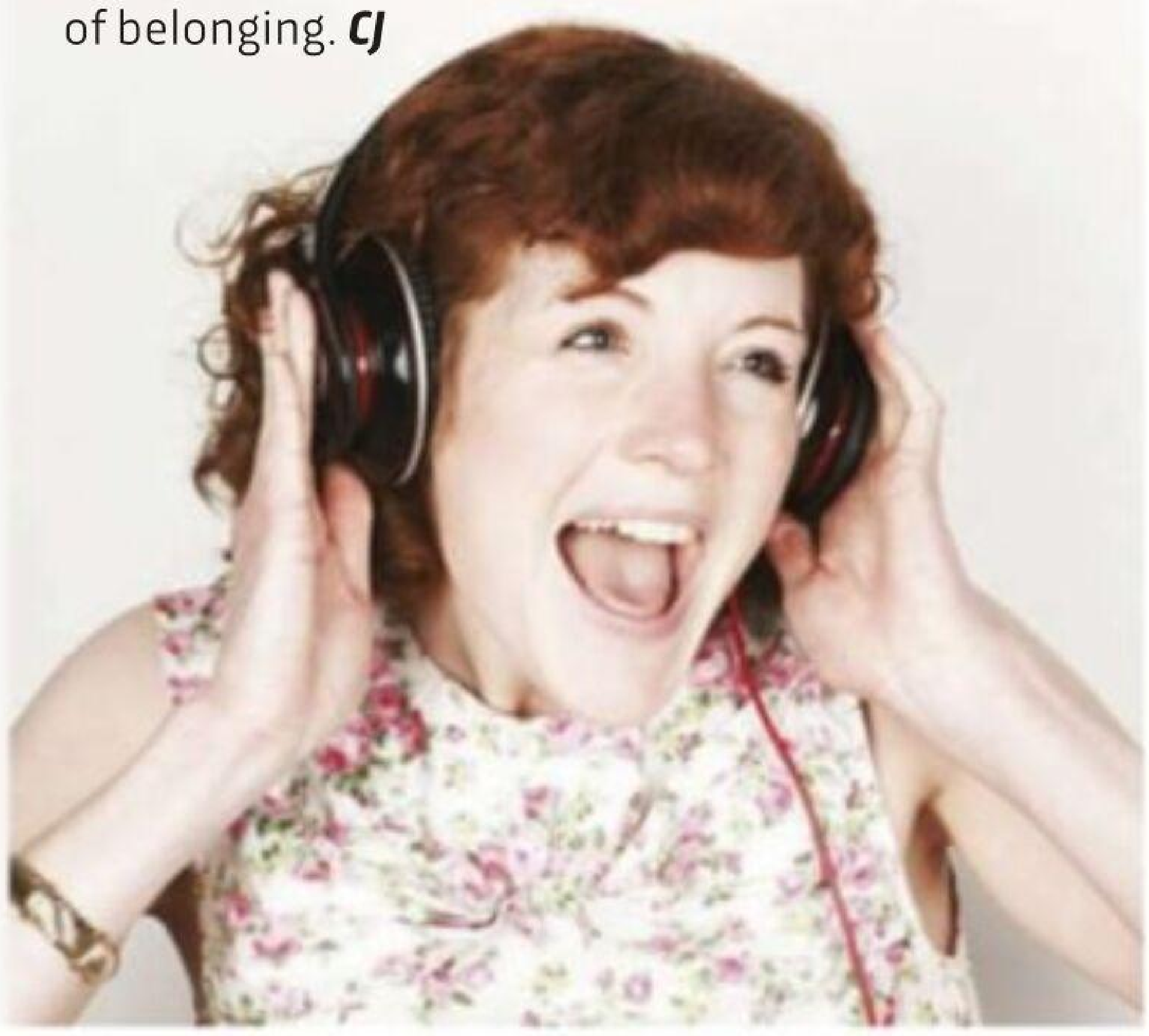
IS IT POSSIBLE TO 'CATCH' AN ACCENT FROM SOMEONE?

If you spend enough time with them, it's almost inevitable. Studies have found that we subconsciously try to imitate speech patterns of strangers, especially if we spend time abroad, where everyone speaks with a strange accent and we are the odd one out. Natural selection seems to have favoured people who have a desire to show empathy and fit in. *LV*

WHY DOES MUSIC MAKE US FEEL GOOD?

At a basic level, it is to do with how our brains have evolved to find it rewarding to look for and find meaningful patterns in sound. Research suggests there is something particularly satisfying about a piece of music that is in some ways familiar, but also contains a few surprises.

Music can also make us feel good by amplifying our mood (think of the 'pleasure' of wallowing in a sad song when you're feeling down); it can also trigger fond or poignant memories. Then there's the social side: singing along with friends to a new tune from your favourite band fosters a powerful sense of belonging. ***CJ***



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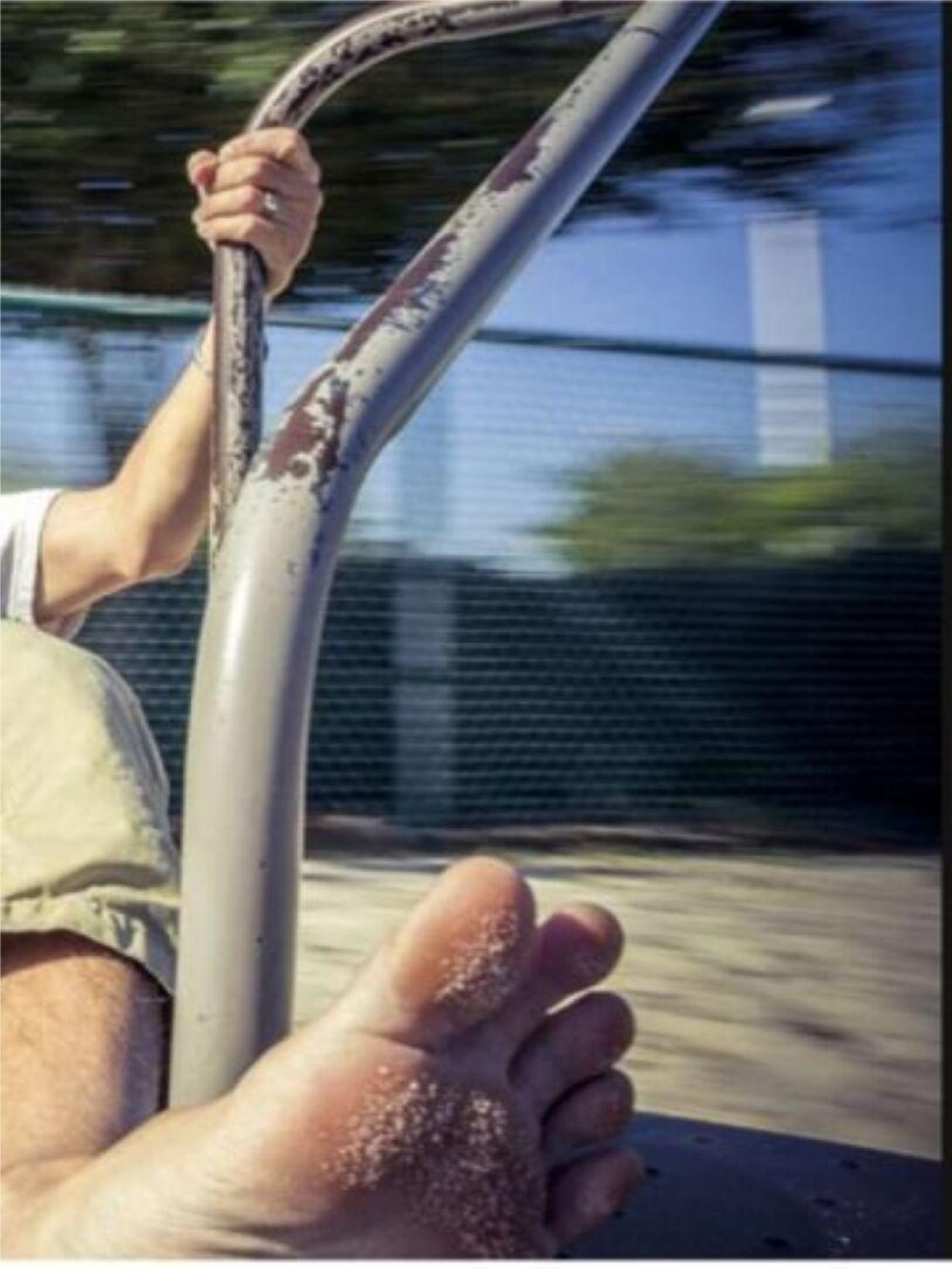


WHY DO WE GET DIZZY WHEN WE SPIN?

When you move your head, the acceleration is detected by hairs lining the side of fluid-filled tubes in your inner ear. If you spin for long enough, your brain gets desensitised to the constant turn signals from your ear, and adjusts to zero them out. When you stop, your ears correctly report zero turning, but your brain is still actively cancelling this out and so it thinks you are now spinning in the opposite direction. ***LV***

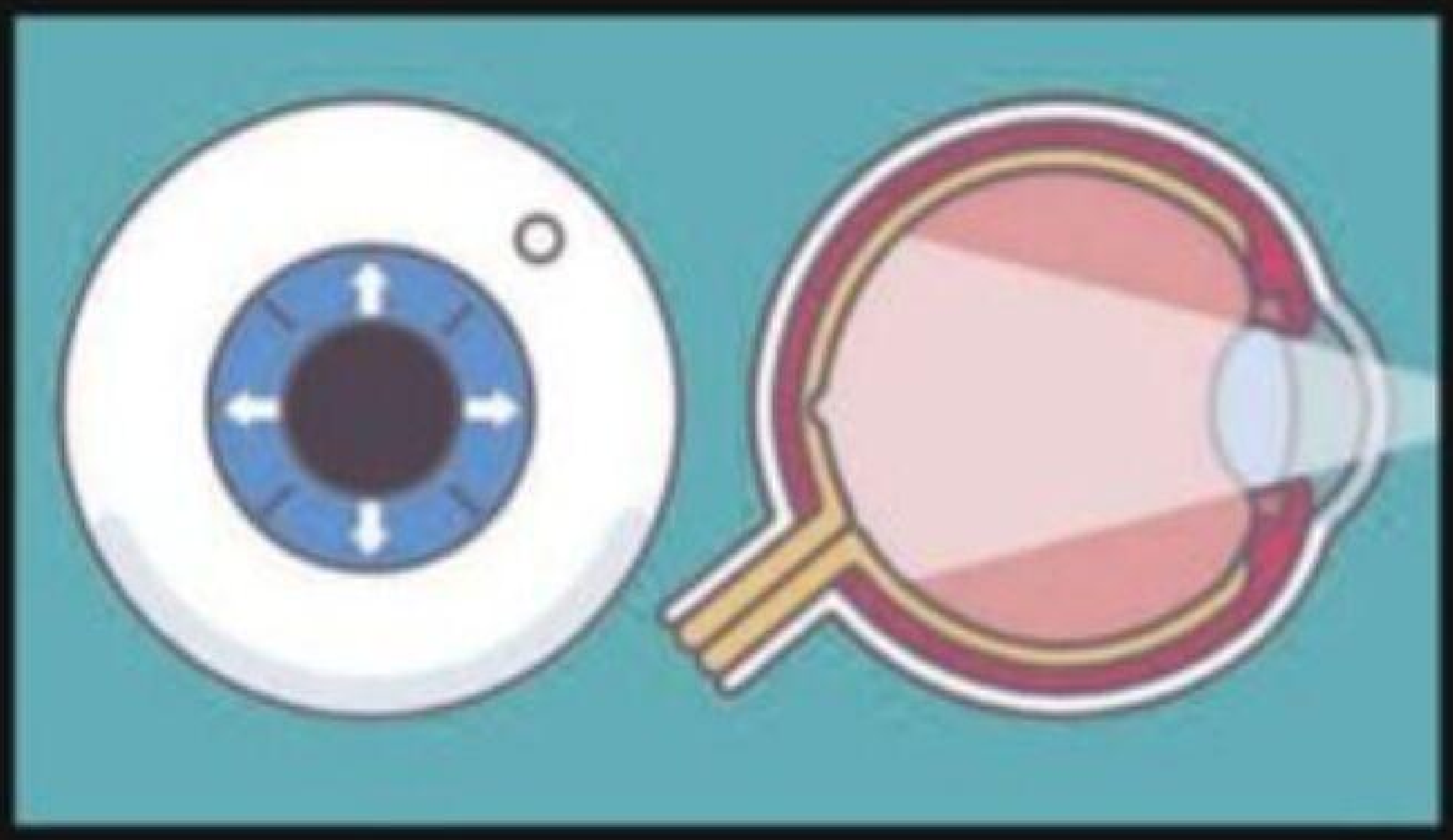
HOW LONG DO SIX PINTS OF LAGER STAY IN MY SYSTEM?

There is no simple answer. The rate at which your body breaks down alcohol depends on your age, sex, weight, metabolism and how much you've eaten. As a general rule, it takes about one hour for your body to break down one 'unit' (10ml of pure alcohol). A pint of low strength lager contains about two units, while a higher strength one has three. So it could take 18 hours or longer for the alcohol from six pints of strong lager to leave your system. In other words, at least some alcohol will still be in your blood the morning after the night before. ***ED***

WHAT HAPPENS IN MY BODY...

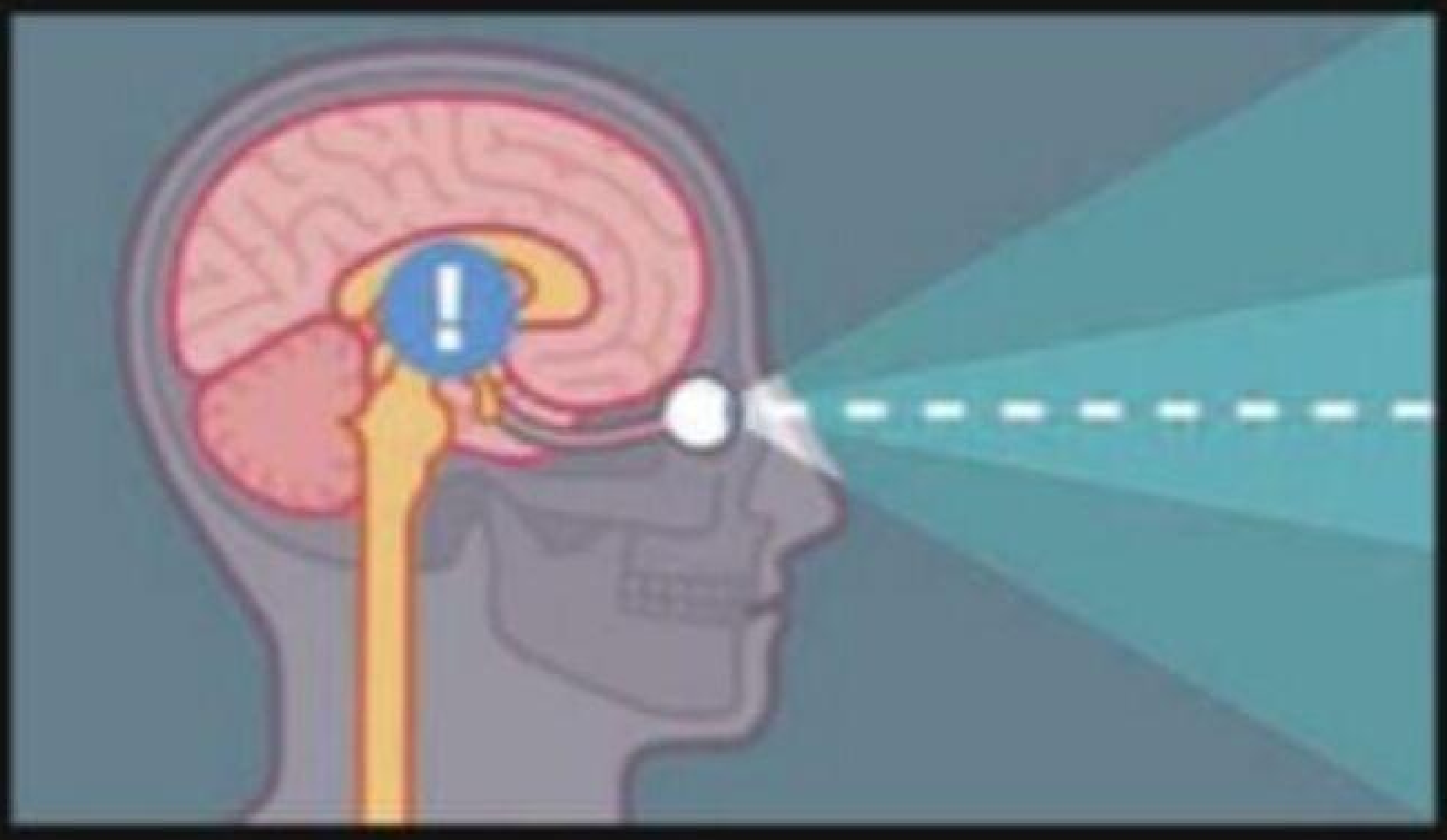
...WHEN I HAVE A PANIC ATTACK?

Humans have evolved behaviours to deal with sudden physical threats, such as predators. These are triggered unconsciously to quickly prepare your body for fighting or fleeing. But modern life is mostly free of marauding bears and this threat response can be accidentally triggered by emotional stress instead. A panic attack is like the smoke alarm going off when you burn the toast, even though the house isn't on fire.



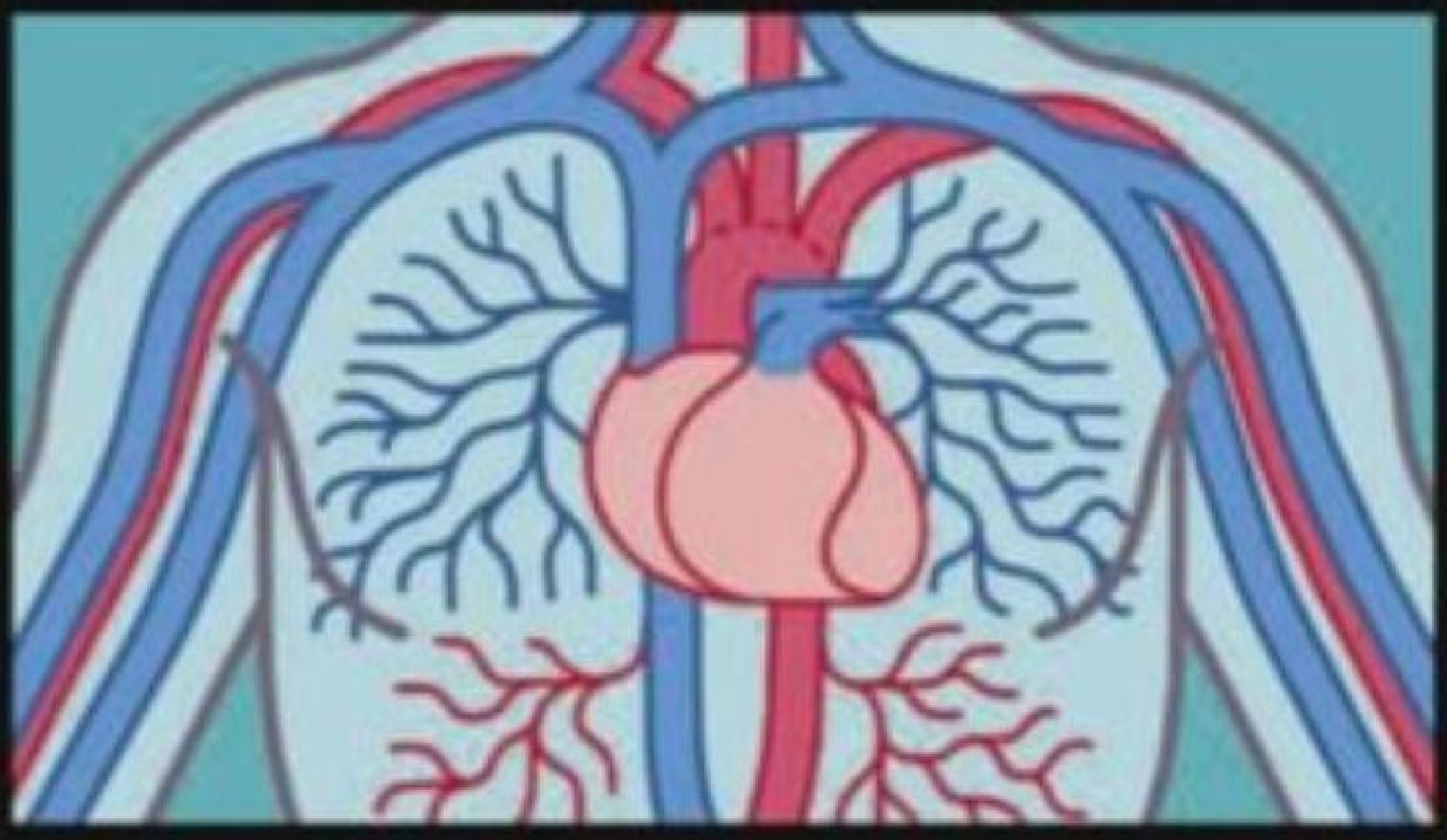
1. EYES

Pupils open wider to increase the light reaching the retina. This boosts vision in low light and improves the 'frame rate' for rapidly moving objects.



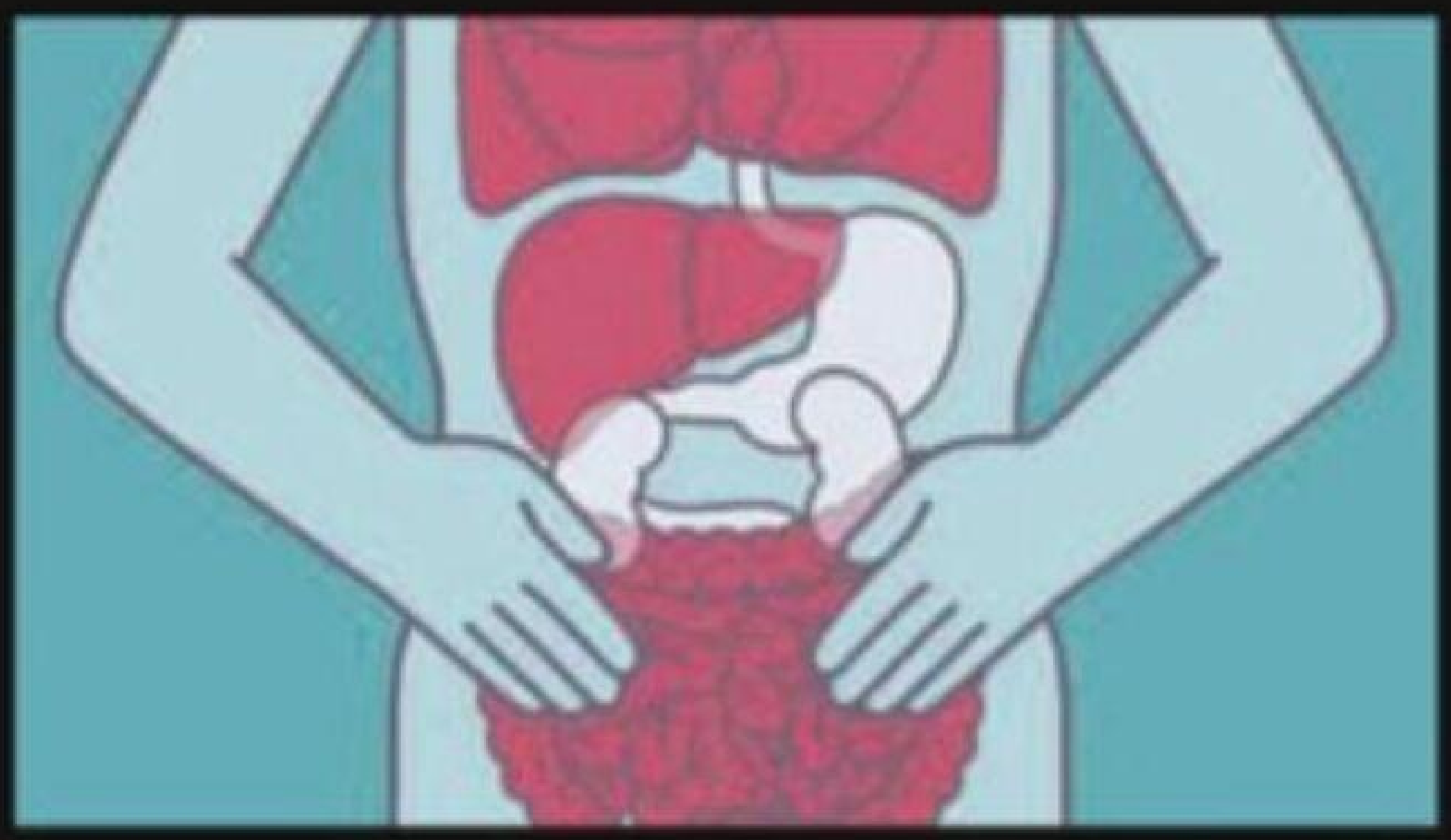
2. BRAIN

Attention narrows to focus exclusively on the perceived source of the threat. If there is no physical danger, this can feel like tunnel vision.



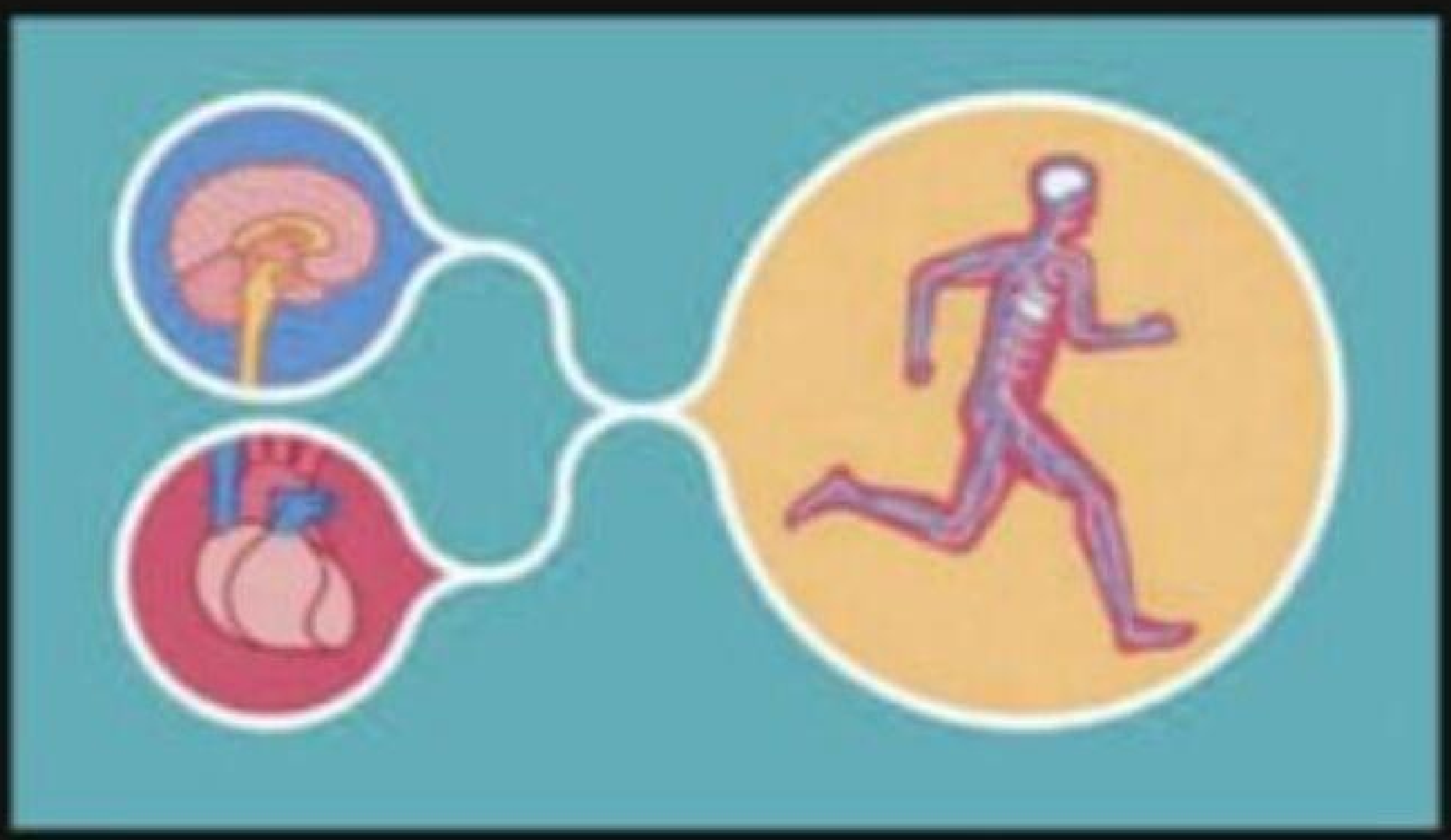
3. HEART

Pulse rate rises. Your chest feels like it is thumping and you hear the sudden swooshing in your ears as your blood flow increases.



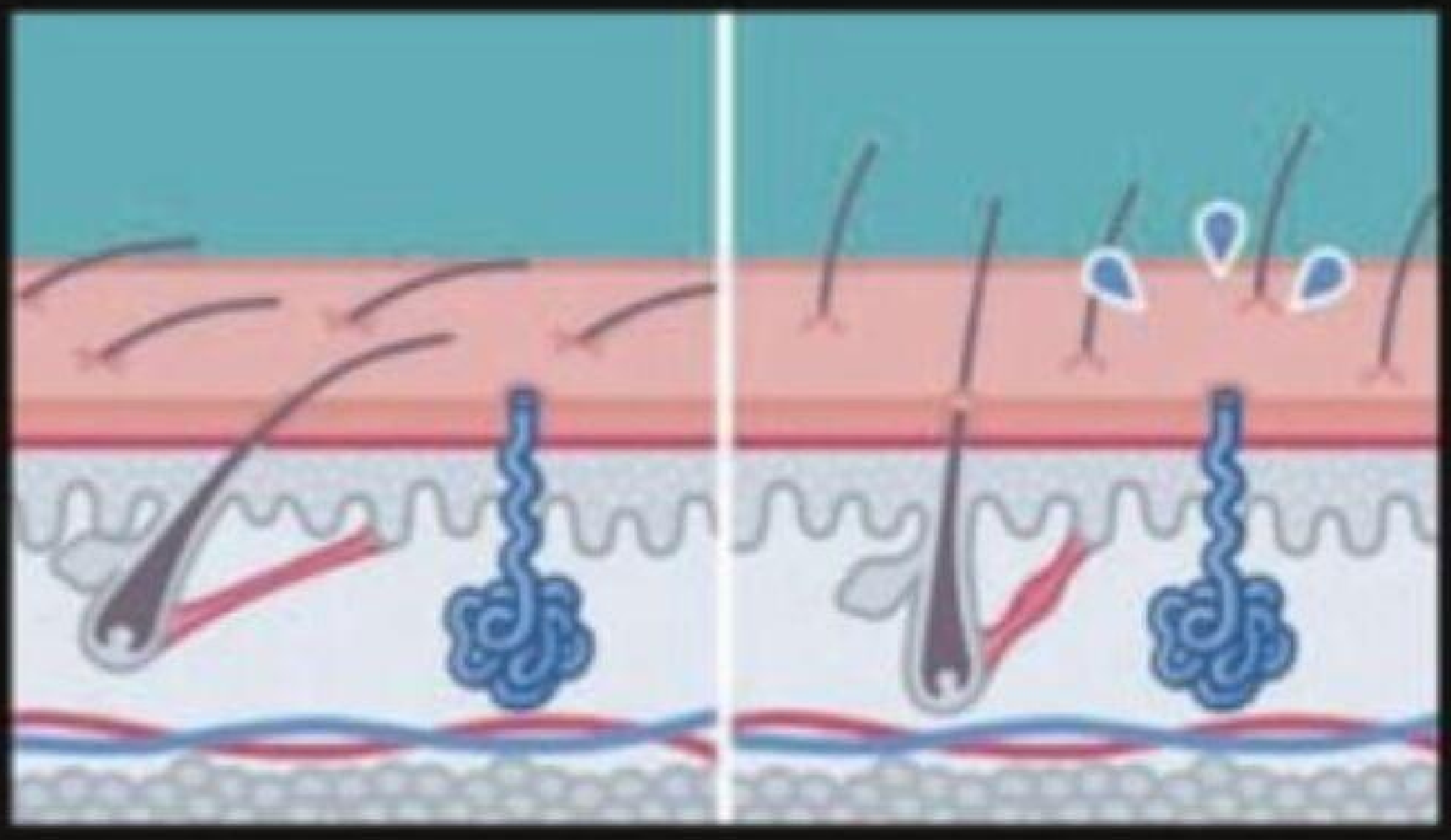
4. STOMACH

Blood is diverted away from your stomach and kidneys, because these are less important in a crisis. This can make you feel sick.



5. LEGS

Your circulation and nervous system are getting your legs ready to run. If you have nothing to flee, the muscles will begin trembling uncontrollably.



6. SKIN

You sweat because your body is preparing to shed the excess heat from sudden exercise. Hair stands on end to make you seem larger to predators.

WHY DO I REMEMBER SOMETHING BETTER IF I READ IT OUT LOUD?

It could be that it helps to hear the information in your own voice, or that there's something memorable about saying the words. A study put these two possibilities to the test using a memory test. The findings suggested that both the act of speaking, and hearing oneself, assist memory – the former because it's a more active process than silent reading, and the latter because hearing oneself speak makes the information more personally salient. ***CJ***

5,000

The number of faces, from family to celebrities, that most people can recall

HOW OLD IS DYSLEXIA?

Many sources will tell you that the first case was reported in 1896 by the English family doctor W Pringle Morgan, who described a 14-year-old boy called Percy with "word blindness". Morgan noted how, despite his intelligence, Percy struggled to read. But the first use of the term 'dyslexia' was actually by the German opthalmologist Rudolf Berlin in 1887, in his case report of a boy with problems learning to read and write. ***CJ***

DOES MILK REALLY BUILD HEALTHY BONES?

The body needs a regular intake of calcium for a range of needs, not least building and maintaining bones. If it doesn't get enough calcium from the diet, it will extract it from your bones. Although some disagree on the importance of dairy products, they are undeniably good sources of absorbable calcium. But healthy bones also require vitamin D and potassium. It's a good idea to boost calcium levels by eating plenty of leafy vegetables, beans and seeds. *ED*

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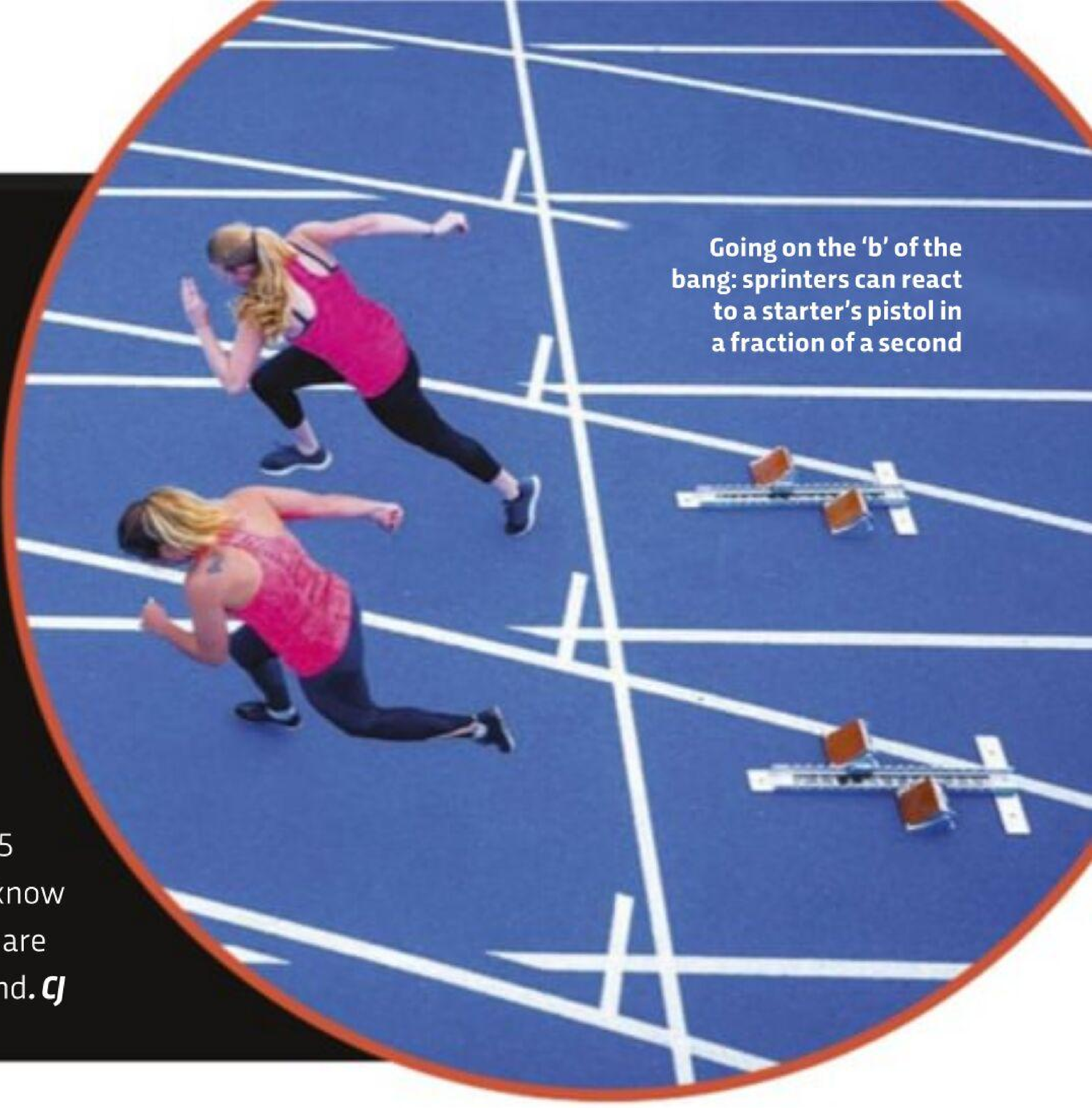
WHAT'S THE SPEED OF THOUGHT?

Scientists have approached this question by timing how long it takes us to become consciously aware of sensory information. By some estimates, we can experience sensory stimuli that's presented for as little as 50 milliseconds (about one 20th of a second). It is thought that our brains can respond to information that's much briefer than this, lasting less than a quarter of a millisecond. In terms of sensing and then responding, a good measure is a sprinter reacting to a starting gun, which can be done in about 150 milliseconds. One limiting factor is how long it takes information to travel down our nerve pathways. In the 19th century, Hermann von Helmholtz estimated this to be 35 metres per second, but we now know that some well-insulated nerves are faster, at up 120 metres per second. ***CJ***



Going on the 'b' of the bang: sprinters can react to a starter's pistol in a fraction of a second

WHY DO I LOSE MY HEARING WHEN I YAWN?

This is due to a muscle in your middle ear called the tensor tympani, which is attached to the small 'hammer' bone that transmits sound from the eardrum. The muscle automatically contracts to reduce our hearing sensitivity in response to a sudden loud sound such as thunder, and it also contracts as we chew, so we aren't deafened by the sound of our own jaw muscles. Yawning also involves jaw movements that trigger the tensor tympani, though, so a side effect is that we get deafer during a yawn. *LV*

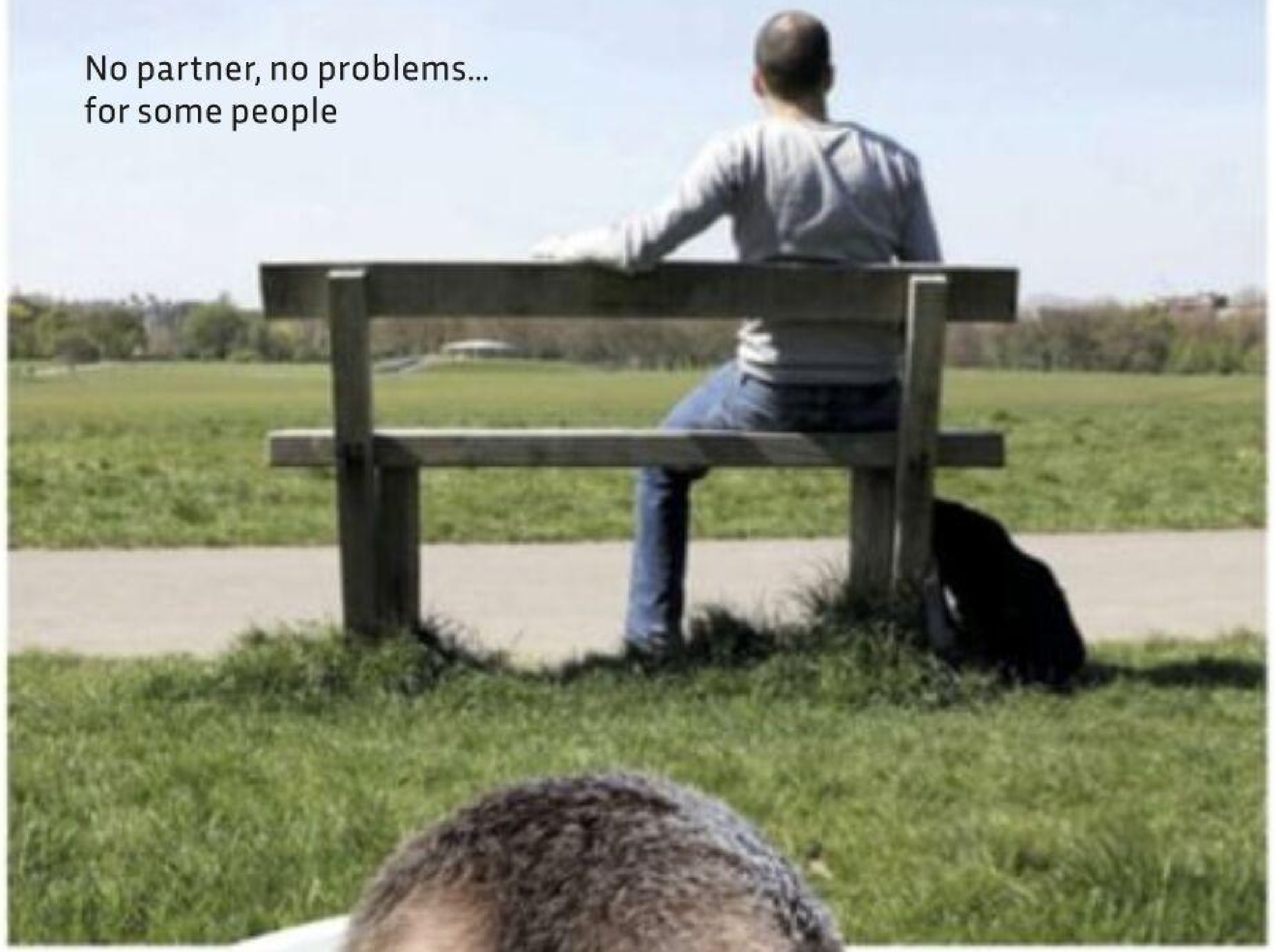
IS THE SUGAR IN FRUIT BAD FOR YOU?

The sugar in fruit is mostly fructose and glucose. Glucose is the primary food molecule, and can be used directly by the cells in your body. Fructose, however, must be converted into glucose before it can be used. This happens in the liver, but there is a limit as to how fast the liver can process fructose. When it is overloaded, it will instead convert the fructose into fat – so high-fructose diets can make you obese. But a diet that's rich in fresh fruit isn't a high-fructose diet. That's because fruits have a lot of fibre and water that slow your digestion and make you feel full. In fact, research has found that apples and oranges are some of the most filling foods per calorie – higher than steak or eggs. So although a medium apple contains 19g of sugar, including 11g of fructose, you will feel less hungry afterwards than if you had the same amount of sugar from a fizzy drink (about half a can of Coke). It's almost impossible to get too much sugar from fresh fruit, but this doesn't apply to fruit juice or dried fruit. They're much easier to binge on. ***LV***

TYPE OF FRUIT		SUGAR
GRAPES *(1 serving, 151g)*		23g
1 MEDIUM APPLE *(182g)*		19g
1 MEDIUM PEAR *(178g)*		17g
PINEAPPLE *(1 serving, 165g)*		16g
1 MEDIUM BANANA *(118g)*		14g
1 MEDIUM PEACH *(150g)*		13g
1 MEDIUM ORANGE *(131g)*		12g
HALF A WHITE GRAPEFRUIT *(118g)*		9g
WATERMELON *(1 serving, 152g)*		9g
STRAWBERRIES *(1 serving, 152g)*		7g
RASPBERRIES *(1 serving, 123g)*		5g
1 MEDIUM TOMATO *(123g)*		3g

IS BEING SINGLE BAD FOR YOUR HEALTH?

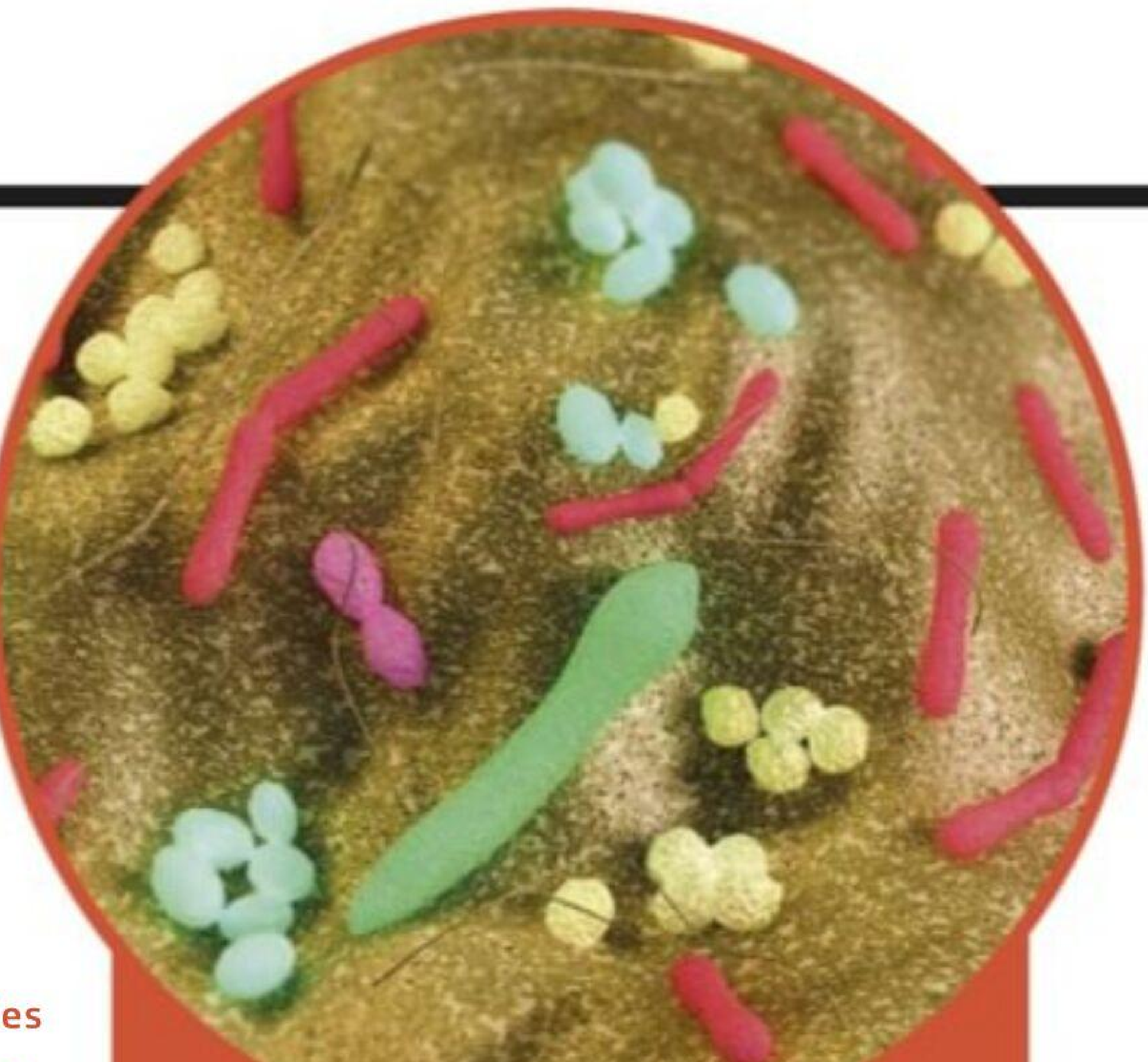
It is sometimes argued that being in a relationship can offer health benefits. The research cited in support of this says that those who are married are, on average, healthier than those who are not. But the situation is likely to be much more complex than this. For example, it's not clear whether being in a relationship offers health benefits or whether there are other explanations for this association. Furthermore, whereas being in a relationship may be linked to certain health advantages, it could bring health risks too. Research suggests that people who are married are more likely to be overweight than those who are not. Finally, one size does not fit all. Whereas being in a happy relationship may bring certain advantages, being in a dysfunctional one is unlikely to do so. ***AGr***



No partner, no problems... for some people

DOES THE BODY NEED SALT?

We can't survive without it. It's crucial for our nervous system to function, our muscles to contract and relax, and for maintaining fluid balance. But the amount that we need is actually very small: less than a quarter of a teaspoon a day. Almost all of us consume more than that and exceeding 6g (a teaspoon) per day could be harmful if you're at risk of, or have, high blood pressure. The best way of reducing salt intake is to eat less processed food. ***ZW***



WHAT PROPORTION OF OUR BODIES IS BACTERIA (AND HOW DO WE MEASURE IT)?

For decades, scientists' best guess was that the body contains 10 times as many bacteria as human cells. But a team from Israel and Canada revisited the calculations in 2016 to estimate that we have a roughly equal number of bacteria and human cells. They based their calculations on the fact that most of our bacteria are found in the colon. Using information from MRI scans, they calculated the colon volume of a 'reference man'. Since there are about 90 billion bacteria per gram of wet stool, they estimated that there are around 38 trillion bacteria in the body, compared with 30 trillion human cells. ***ED***

GETTY IMAGES X2, SCIENCE PHOTO LIBRARY, ALAMY

An effective method of oral male contraception may soon be on the market

IS THERE A MALE CONTRACEPTIVE PILL YET?

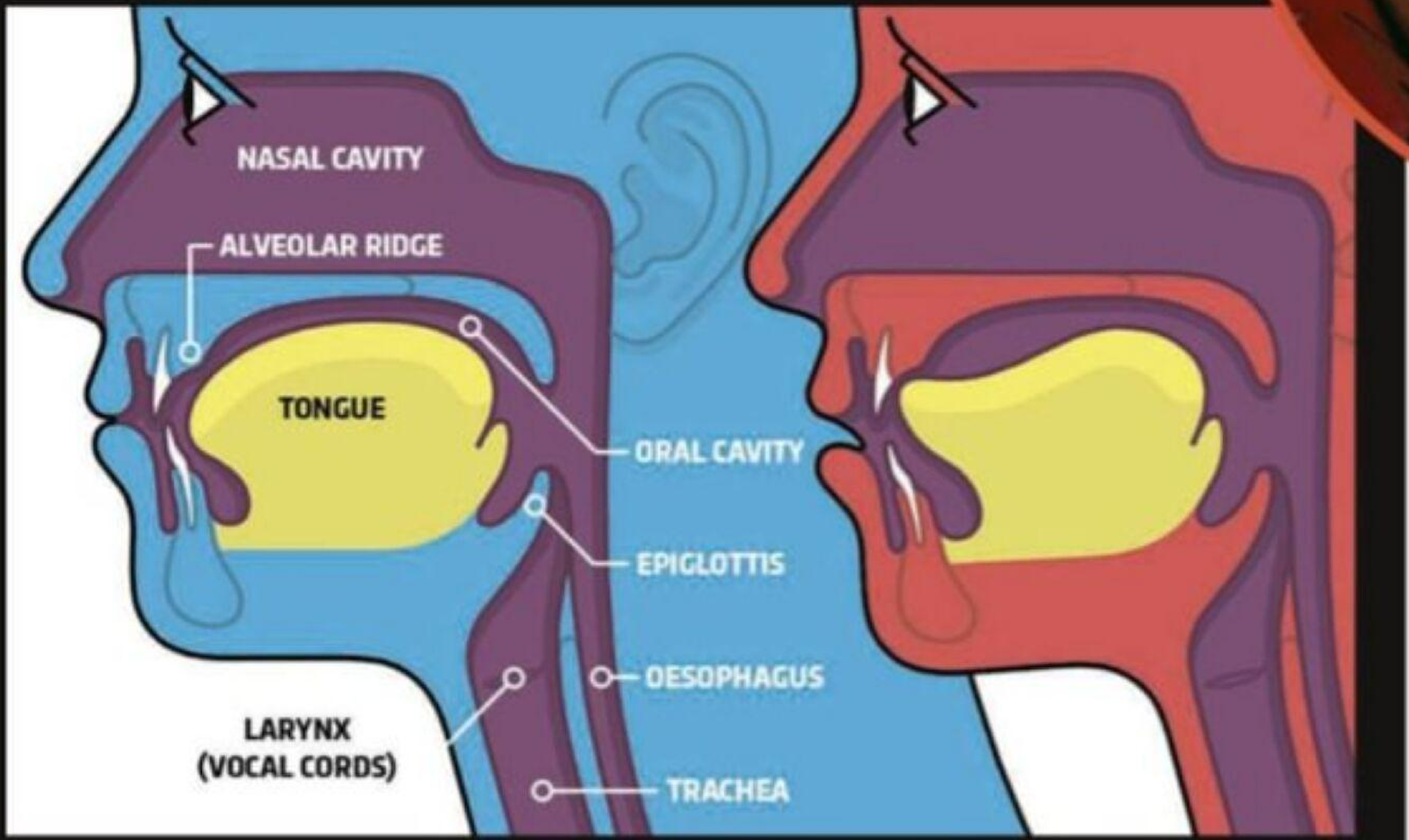
We're getting closer. Dimethandrolone undecanoate, or DMAU, is still undergoing trials, but initial findings suggest that it dramatically suppresses sperm production, without the unwanted side effects of previous pills, such as breast enlargement, low sex drive or liver inflammation. DMAU is a single molecule, but – like female contraceptive pills – it combines the biological properties of two types of sex hormone. The main ingredient is dimethandrolone, which is a synthetic 'androgen' with some of the properties of testosterone. But DMAU also acts as a 'progestogen'. In men, this suppresses the other sex hormones, such as testosterone and oestrogen, but without feminising side effects. The result is a reduction in sperm production. DMAU also contains the long-chain fatty acid undecanoate, which increases the amount of time the drug spends in the body, so that one pill will last all day. ***LV***

WHY DO MY FINGERNAILS GROW FASTER IN HOT WEATHER?

In 1941, American doctor William Bennett Bean began a 35-year study of his own fingernail growth, concluding that climate, season and geographical location have no effect on growth rate. Other studies, however, have found a slight increase in growth during the summer – probably due to increased blood supply to the fingertips. But if you notice a sudden change while on holiday, it's more likely that your nails just aren't being worn away so fast while you're relaxing by the pool and the actual growth rate hasn't increased very much. ***LV***

Shridhar Chillal stopped cutting the nails on his left hand in 1952 and finally had them cut short in July 2018. The record-breaking nails had a combined length of more than nine metres

WHY CAN'T EVERYONE ROLL THEIR 'R'S?



It's a misconception that some people can't roll their 'r's. In countries with 'r' rolling languages (Spain, for example) many people learn the skill in childhood. But those yet to master the skill need only to practise. The key is to tuck your tongue behind your upper front teeth, resting the tip on the 'alveolar ridge' – the small, bony protuberance behind the teeth – and relax your tongue so it vibrates as the air flows past. Rolling an 'r' is similar to blowing a raspberry. In fact, some language experts suggest beginning training by blowing a raspberry while humming. Be prepared for hours of practise, but perhaps not in the office, unless you have understanding colleagues! ***ED***

WHY DO FOOTBALL PLAYERS SPIT SO MUCH?

Several studies have shown that exercise increases the amount of protein secreted into the saliva, especially a kind of mucus called MUC5B. This mucus makes the saliva thicker, which makes it harder to swallow, so we spit it out. It isn't clear why we produce more MUC5B when exercising, but it may be because we breathe through our mouths more and the mucus stops the mouth from drying out. Some sports, such as basketball and tennis, penalise players for spitting, but not football and rugby. ***LV***

IS MSG BAD FOR YOU?

MSG, or monosodium glutamate, certainly has a bad reputation, conjuring up images of takeaways and highly processed foods. But this 'umami' flavour enhancer – first extracted from seaweed in 1908 – contains only sodium (one of the ingredients of common table salt) and glutamic acid, which is naturally found in foods such as mushrooms, tomatoes and Parmesan cheese. A popular belief is that MSG can cause headaches and a generally 'icky' feeling known as 'Chinese restaurant syndrome'. But this is a myth: scientists have found no evidence linking typical MSG amounts to headaches, or any other health problems for that matter. Just like salt, a sensible amount is perfectly safe and tasty too. *GY*

Cover them or face the fact they'll gradually fade – tattoo ink is susceptible to the effects of sunlight and your immune system

ACUTE GRAPHICS, GETTY IMAGES X4

WHY DO TATTOOS FADE?

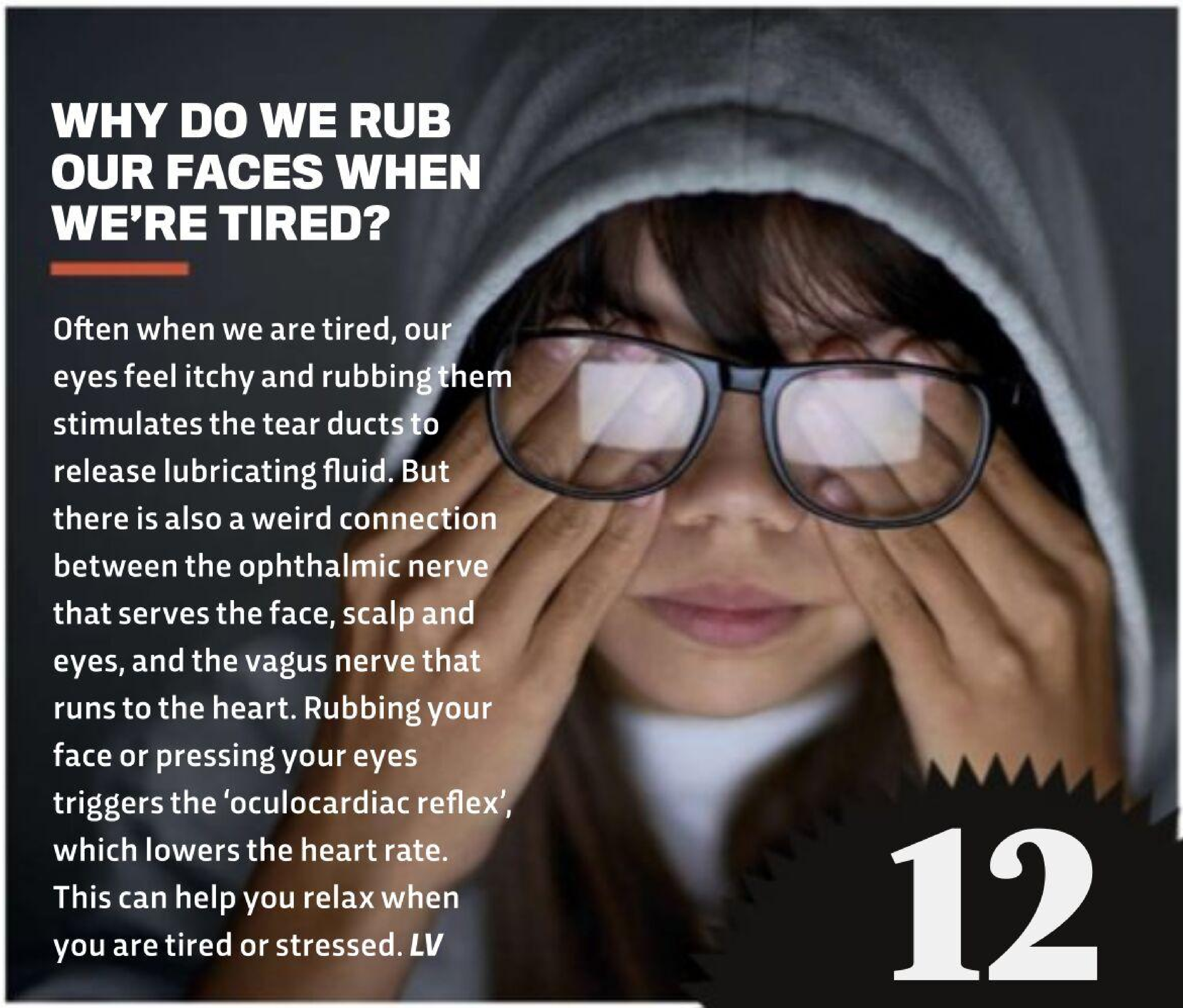
Tattoo needles deposit ink beneath the epidermis. This is deep enough that the ink won't be immediately shed with the skin cells of the upper layers, but macrophage cells from your immune system will gradually absorb the ink and disperse it. And the UV frequencies in sunlight are energetic enough to break down the ink molecules over time, so tattoos that are always exposed – such as on the fingers or face – fade quicker than those covered by clothing. *LV*

500,000

The number of worldwide annual deaths attributed to eating industrially produced trans fats, according to the World Health Organisation

IS IT POSSIBLE TO HAVE THE FLU AND A COLD AT THE SAME TIME?

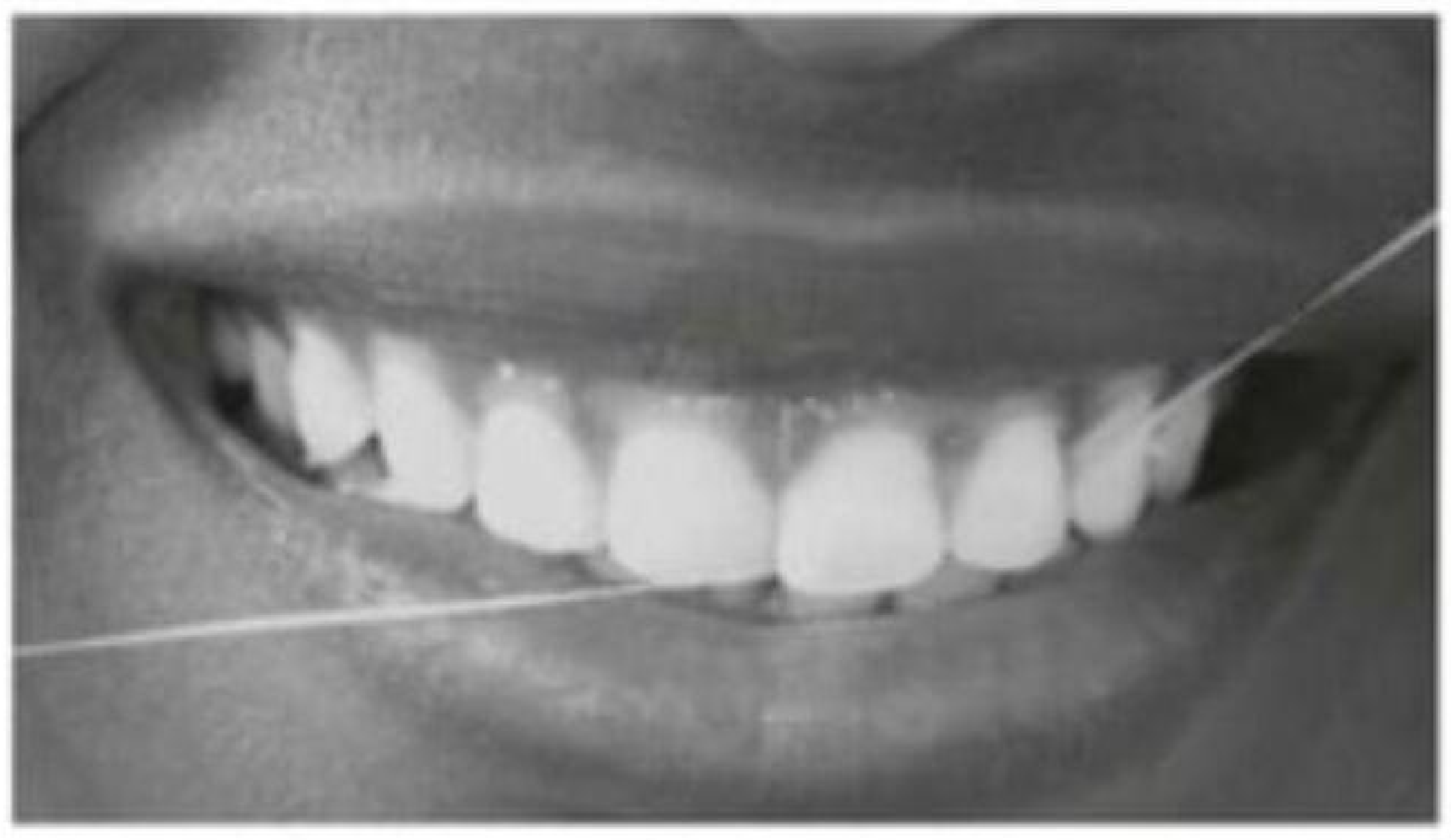
Flu and common colds are caused by different families of viruses, so it's possible to have both in your body at the same time. But a lot of your immune response to one virus also makes conditions inhospitable for any other virus, so it is less likely that a second infection will take hold while you are fighting the first. This so-called antiviral state doesn't protect you against bacterial infections though. A lot of the deaths from flu are actually due to secondary bacterial pneumonia infections that can take hold while your immune system is busy fighting the flu. *LV*



WHY DO WE RUB OUR FACES WHEN WE'RE TIRED?

Often when we are tired, our eyes feel itchy and rubbing them stimulates the tear ducts to release lubricating fluid. But there is also a weird connection between the ophthalmic nerve that serves the face, scalp and eyes, and the vagus nerve that runs to the heart. Rubbing your face or pressing your eyes triggers the 'oculocardiac reflex', which lowers the heart rate. This can help you relax when you are tired or stressed. ***LV***

DOES FLOSSING YOUR TEETH REALLY MAKE A DIFFERENCE?



For years, dentists have told us to floss as well as brush our teeth. And it seems to make sense: less gunk between our teeth should lead to less decay. Yet surprisingly, there's little evidence it's true, as it's never been put to the test in a large clinical trial. Some small studies have found that flossing helps combat gum disease, but there's no compelling evidence that it also stops tooth decay. So does that mean it's pointless? Not at all. First, gum disease is a major cause of tooth loss. And second, just because researchers haven't done a proper study, it doesn't mean flossing can't also prevent tooth decay: the absence of evidence doesn't mean there's no effect. ***RM***

12

The amount, in grams, of salt you'd have to eat daily before experiencing any adverse impact on health, according to research at McMaster University, Canada. Only in China does the average daily diet exceed this level

DOES BLUSHING HAVE ANY EVOLUTIONARY PURPOSE?

Charles Darwin called blushing "the most peculiar and most human of all expressions", but it would be more than 125 years before we had any hard data on what evolutionary function blushing might serve. We now know that when people blush after a transgression or mishap, their state of shame and embarrassment is considered more intense by onlookers, and as a consequence they are viewed more favourably – perhaps because it signals their realisation and regret that they have transgressed. In one study, Dutch psychologists found that cheaters in a financial game who blushed were soon trusted again. So blushing seems to have evolved as a non-verbal way to help us bond with others by showing our concern for social rules. ***CJ***

GETTY IMAGES X5

IS IT POSSIBLE TO GET PREGNANT WHEN YOU'RE ALREADY PREGNANT?

Getting pregnant while already pregnant is called superfoetation. It's been reported in mammals, including mice and rabbits, and there have been a handful of possible cases in humans. In 2017, a US woman acting as a surrogate mother was reported to have discovered that one of the twins that she was carrying was in fact her biological son. She had apparently become pregnant roughly three weeks after her surrogate conception. For superfoetation, a woman has to ovulate again after becoming pregnant. This is rare because hormonal changes after conception usually prevent the ovaries from releasing another egg. What's more, a mucus plug forms in the cervix during pregnancy, which should prevent sperm from swimming up. ***ED***

IS IT POSSIBLE TO SLEEP WITH YOUR EYES OPEN?

Not normally, but there is a condition called nocturnal lagophthalmos where a sufferer is unable to shut their eyelids when asleep. According to one review, this occurs in up to five per cent of adults. This can be due to a variety of factors, including protruding eyes or abnormalities of the eyelids. Noctural lagophthalmos can lead to sore eyes and more severe problems, such as ulcers on the cornea. Do talk to your doctor if you're waking up with red or sore eyes or have been told by someone that you sleep with your eyes open. ***AGr***

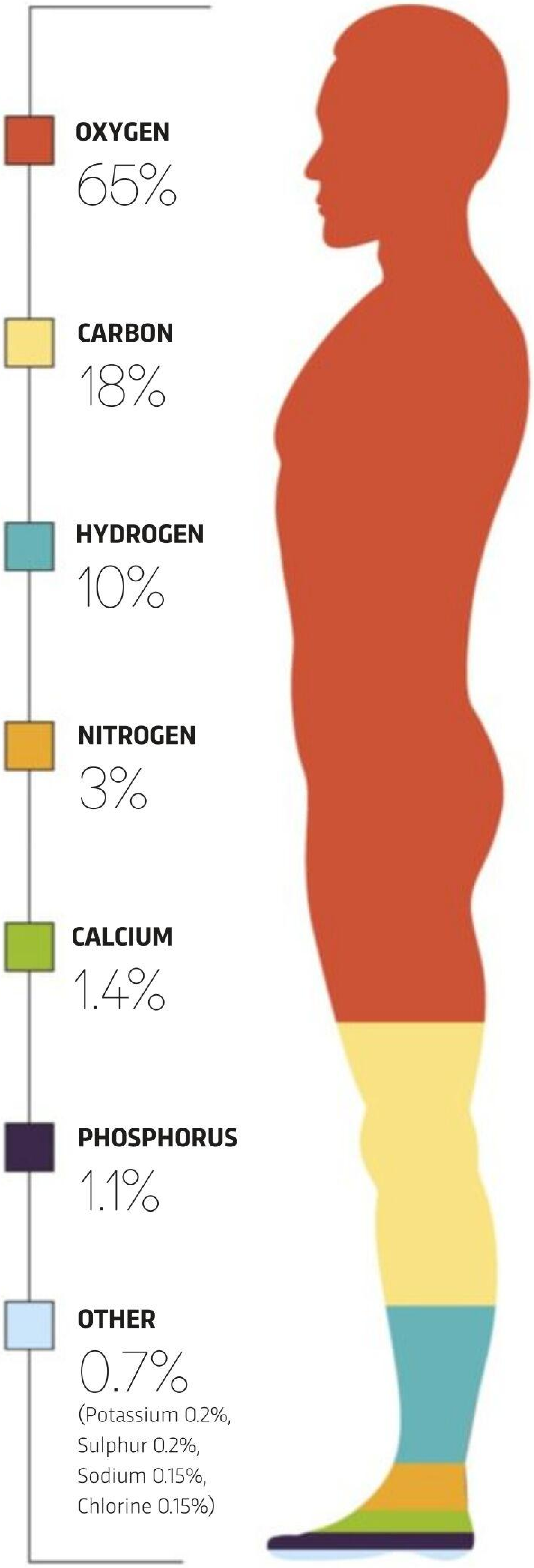
WHY DOES TIME SEEM TO GO SLOWER WHEN WE'RE BORED?

Although we feel sluggish and tired when we're bored, at a physiological level it's actually a 'high arousal' state (as measured by a faster heart rate). In turn, it's well-established that greater arousal speeds up our brain's 'internal clock', so that we feel that more time has passed than actually has. Another theory is that the apparent slowing down of time is a kind of signal our brain sends to itself to convey that the current situation is unfulfilling and we should do something else. ***CJ***

TOP 10

ELEMENTS IN THE HUMAN BODY

(BY PROPORTION OF TOTAL BODY MASS)



WHY DID WE EVOLVE AN IMAGINATION?

Imagination underlies our ability to anticipate different futures and to reflect on alternative pasts. Arguably, it's what distinguishes us most profoundly from other animals. It means we can learn from past experiences ("If I'd taken a spear with me, I could have caught the deer") and we can hypothesise about the possible outcomes of future scenarios ("If I trek across the desert without any food or water, I will get hungry and thirsty"). This makes us incredibly adaptive and is the secret to our superlative planning and problem-solving skills. Once imagination evolved, it also unlocked the gifts of storytelling, fantasy and wonder. ***CJ***

WHY ARE CLOWNS SO SCARY?

For many people, there is something disturbing about a clown's make-up that renders their facial expression as an unnatural, fixed grin or smile. This means we can't read their true emotions, putting us on edge. It's probably no coincidence that many of the most infamous horror characters also conceal their faces in some way – think of the *Scream* mask or Leatherface from *The Texas Chainsaw Massacre*. When a clown also behaves aggressively or menacingly, the contrast with their playful costume and grinning features just adds to the creepiness. But context is everything: children can find friendly, silly circus clowns hilarious. ***CJ***

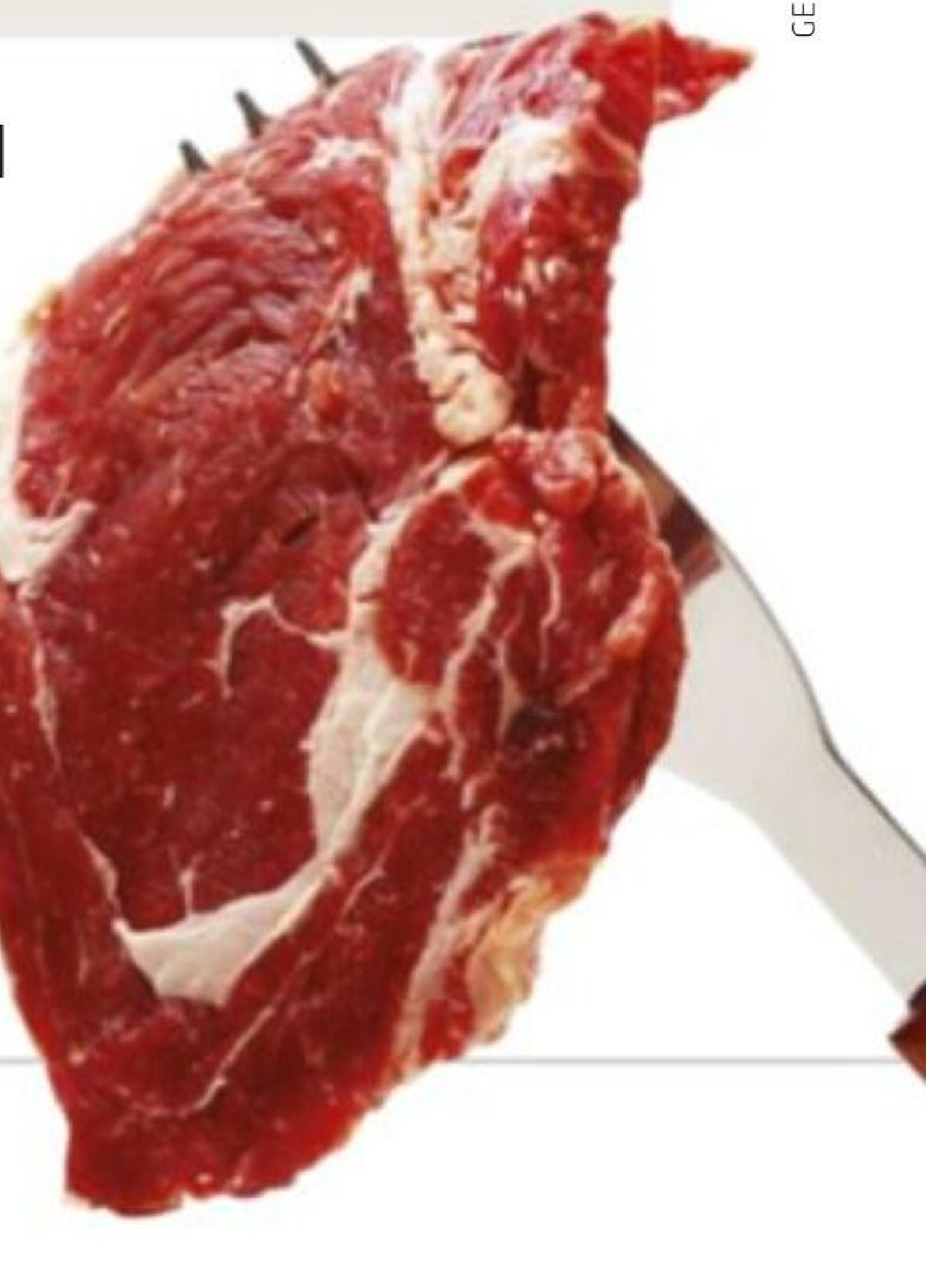
DO BABIES HAVE NIGHTMARES?

It's impossible to know for sure, because babies can't tell us. But given the cognitive abilities of babies, experts believe that they do not experience nightmares. Instead, a baby may wake up crying if they're hungry or uncomfortable. They can occasionally appear confused or fearful when aroused from deep sleep. Nightmares typically occur during rapid eye movement (REM) sleep, and are more common later on when the child has developed a richer understanding of the world. ***AGr***

GETTY IMAGES X6, RAJA LOCKEY

WHAT WOULD HAPPEN IF A PERSON ATE MEAT AND NOTHING ELSE?

Not much in the short term. In a 1928 study, two men ate only meat for one year (under medical supervision). At the end of it they showed "no specific physical changes in any system of the body". Today, fans of a 'carnivore diet' claim it brings weight loss and improves digestive health. But with so much evidence of plant foods' anti-cancer effects, the jury is out on whether a meat-only diet is actually healthy in the long term. ***ED***



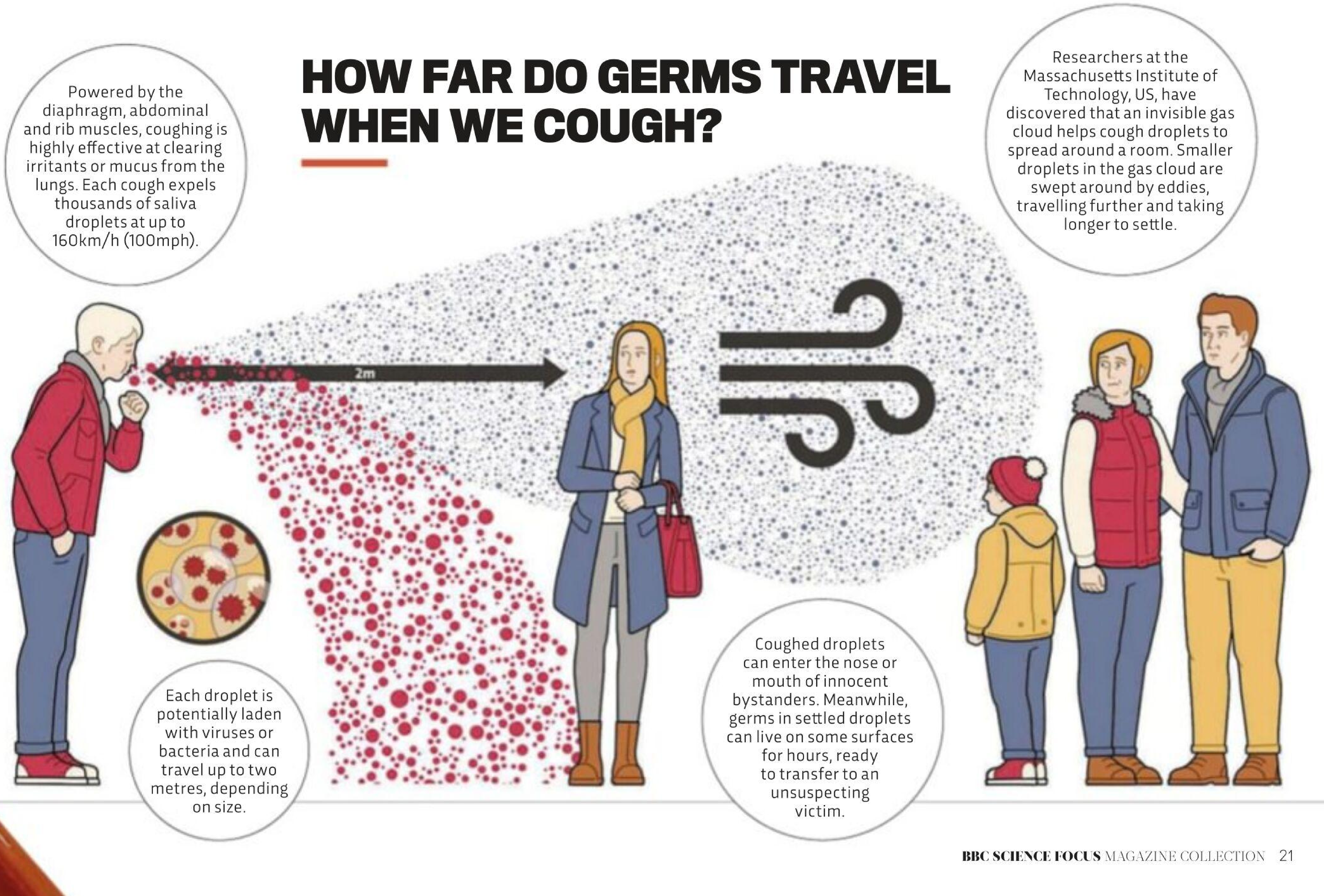
DOES SEA AIR REALLY MAKE YOU SLEEP BETTER?

Take a coastal walk and the chances are that you will sleep better, according to a 2015 study by the UK's National Trust. But there is no evidence that sea air, in itself, will make you sleep better. At one time, people attributed their sleepiness to certain ions or ozone in sea air. In reality, we probably sleep better after a trip to the seaside because we have had a satisfying amount of exercise and have been lulled by the rhythmic sound of the waves. Those that live their daily lives by the seaside don't tend to report improved sleep. ***ED***

CAN HUMANS HIBERNATE?

There are apocryphal stories of medieval Russian peasants surviving the winter famine by spending six months almost constantly asleep. But true hibernation is more like extended hypothermia than sleep and there are lots of serious side effects. Hibernating mammals accumulate mucus in their lungs, and suffer memory loss and suppressed immune systems. Medically induced hypothermic comas of up to two weeks have been used to treat brain injuries, but tests on healthy humans are a long way off. ***LV***

HOW FAR DO GERMS TRAVEL WHEN WE COUGH?



Powered by the diaphragm, abdominal and rib muscles, coughing is highly effective at clearing irritants or mucus from the lungs. Each cough expels thousands of saliva droplets at up to 160km/h (100mph).

Researchers at the Massachusetts Institute of Technology, US, have discovered that an invisible gas cloud helps cough droplets to spread around a room. Smaller droplets in the gas cloud are swept around by eddies, travelling further and taking longer to settle.

Each droplet is potentially laden with viruses or bacteria and can travel up to two metres, depending on size.

Coughed droplets can enter the nose or mouth of innocent bystanders. Meanwhile, germs in settled droplets can live on some surfaces for hours, ready to transfer to an unsuspecting victim.

DA-61
DA-61

EYE OPENER

ATACAMA DESERT, CHILE

What is this?

The Milky Way forms a shimmering arc above the Atacama Large Millimeter/submillimeter Array (ALMA), a cluster of 66 radio telescopes that are studying light from some of the oldest galaxies in the Universe. To reduce the amount of light absorbed by the vapour in Earth's atmosphere, these telescopes have been built 5,000m above sea level in one of driest places on the planet. The conditions here are ideal, as not only is light absorption reduced but there's also very little light pollution or radio interference.

Just to the right of the nearest telescope, you can see the kite-shaped group of four stars known as the Southern Cross.

P HORÁLEK/ESO

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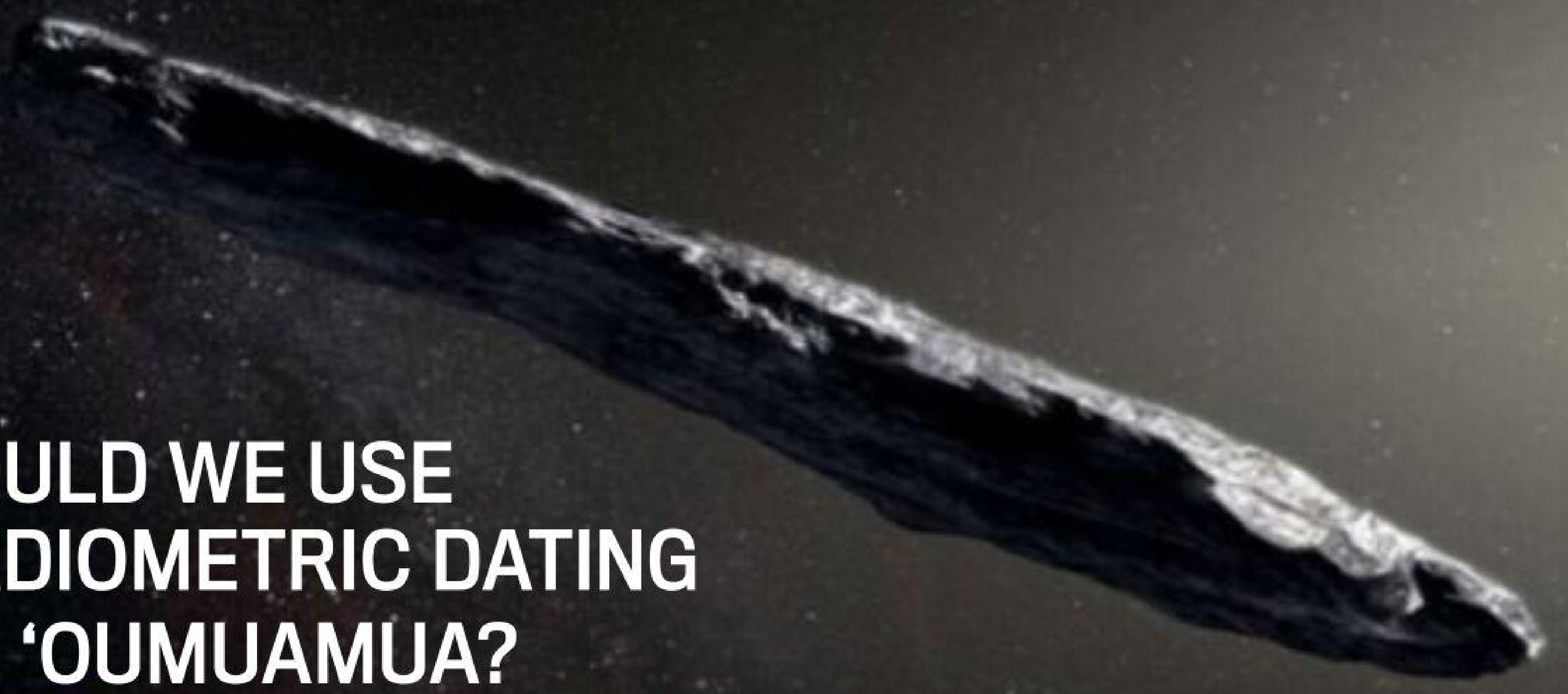
WHY DO ASTRONAUTS ALWAYS USE WHITE SUITS?

Space is a dangerous environment and presents extremes of both hot and cold for the human explorer. To allow spacesuit cooling (and heating) systems to work most efficiently, they are made of material that reflects much of the incident radiation (mostly sunlight) that falls on them; hence, they are white. Another reason for using white material is it this helps astronauts to be visible to crew members, even in the darkness of the Earth's shadow. ***AGu***

High-vis clothing: should you run into trouble on a space walk, it's best to be easy to spot

SPACE

ASTEROIDS, ASTRONAUTS, SPACE JUNK, MICROGRAVITY, EXOPLANETS, BLACK HOLES, ROCKETS, PLANETS AND MOONS…

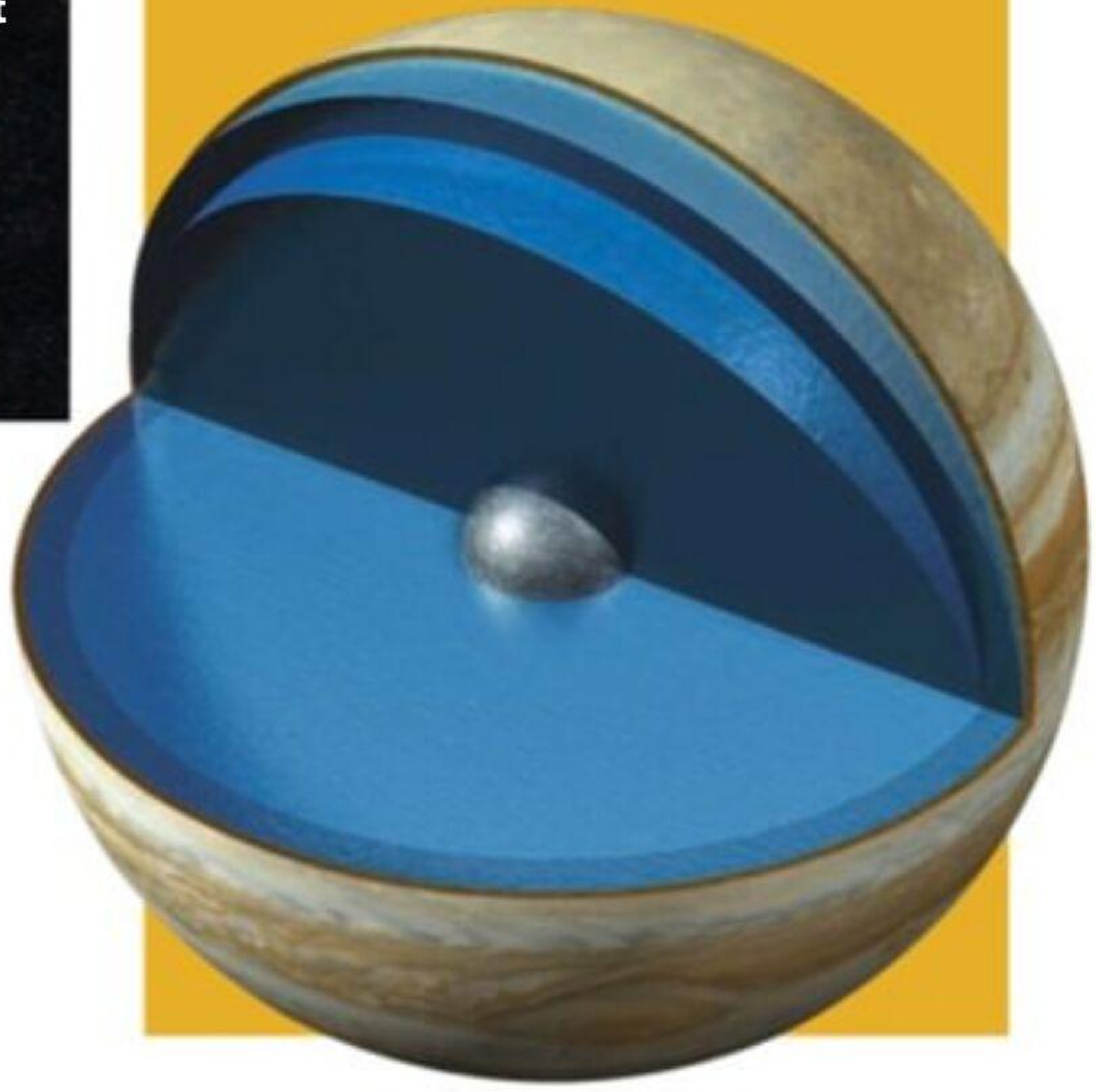


COULD WE USE RADIOMETRIC DATING ON 'OUMUAMUA?

Discovered in October 2017, 'Oumuamua was the first object of interstellar origin found in the Solar System. It is a fascinating object; an elongated red rock about 230 metres long, by 35 metres wide, but its origin is a mystery. Radiometric dating has been used to date meteorites found on Earth and could be useful for dating 'Oumuamua too. For such a study the rubidium-strontium or samarium-neodymium isotope ratios would normally be measured by mass spectrometer. Assuming that a sample of 'Oumuamua could be returned to Earth uncontaminated, that there are sufficient quantities of the isotopes present and that no physical processes have altered the isotope ratios since formation, a reasonable estimate of the age of 'Oumuamua should be possible. *AGu*

WHAT IS AT THE CENTRE OF A GAS GIANT LIKE JUPITER?

This is one of the key questions astronomers hope to resolve with data from NASA's Juno mission, currently orbiting Jupiter. Jupiter's atmosphere is made up of around 90 per cent hydrogen and 10 per cent helium, so computer models suggest its core may be made from metallic hydrogen, a bizarre form of the element thought to exist at extreme pressures. ***RM***



IS SPACE A PERFECT VACUUM?

A vacuum is defined as a space devoid of all matter. In the Solar System, space contains on average five atoms per 1cm^3. Interstellar space, between stars, contains around one atom per 1cm^3, while intergalactic space, between galaxies, contains 100 times less. Ultimately, a perfect vacuum isn't possible because quantum theory dictates that energy fluctuations known as 'virtual particles' are constantly popping in and out of existence, even in 'empty' space. ***AGu***

NASA, ESO, SCIENCE PHOTO LIBRARY

WHO REALLY DISCOVERED...?

THE HEAT FROM THE BIG BANG?

ROBERT WILSON

ARNO PENZIAS

ANDREW MCKELLAR

In 1964, physicists Arno Penzias and Robert Wilson at the Bell Telephone Laboratories in New Jersey were investigating interference that was affecting a horn-shaped antenna built for satellite communications. Their analysis suggested it was emanating from an incredibly feeble source of heat, amounting to just a few degrees above absolute zero (-273°C) – and bizarrely, it seemed to be coming from everywhere in the sky at once.

When the pair described their findings to astrophysicists at nearby Princeton University, the truth emerged: Penzias and Wilson had detected the heat left over from the Big Bang. The momentous discovery garnered the pair a share of the Nobel Prize for physics in 1978.

But by then, it was clear they weren't the first to detect this primordial heat. In 1940, Canadian astronomer Andrew McKellar found molecules in space whose properties revealed the temperature of their surroundings. He showed that these suggested the whole of space was a few degrees warmer than absolute zero, but the significance of this was missed because theorists had yet to work out the consequences of the Big Bang in detail. Sadly, McKellar never lived to see his claim vindicated: he died in 1960, aged just 50. *RM*

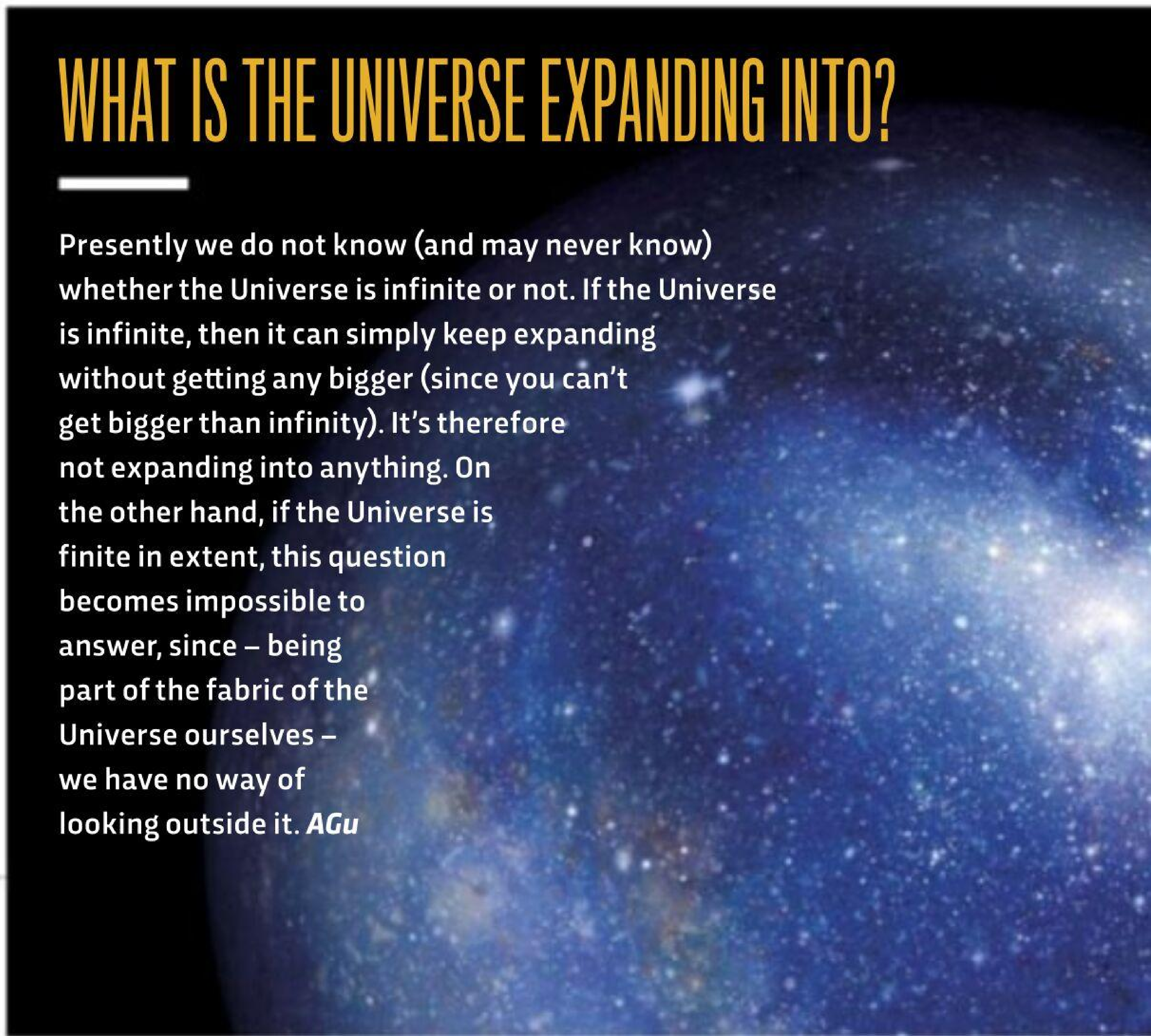
The heat left over from the Big Bang is known as the cosmic microwave background

HOW SERIOUS A PROBLEM IS SPACE JUNK?

Debris in space, which has been accruing since the 1950s, is a well-documented problem. NASA estimates there are roughly 22,000 objects larger than 10cm in diameter in near-Earth orbit. There are likely tens of millions of smaller pieces, too. Most of this junk is moving at extremely high speeds – up to seven times the speed of a bullet. At that speed, an object no bigger than a penny could easily destroy a spacecraft. Even more worryingly, a 'critical mass' of space junk may be only a few decades away, where one major collision results in an uncontrollable chain reaction, causing untold damage. Possible clean-up solutions include gathering the debris using nets, harpoons, laser beams or mini-satellites, or forcing the junk to burn up in the atmosphere. ***AGu***

WHAT IS THE UNIVERSE EXPANDING INTO?

Presently we do not know (and may never know) whether the Universe is infinite or not. If the Universe is infinite, then it can simply keep expanding without getting any bigger (since you can't get bigger than infinity). It's therefore not expanding into anything. On the other hand, if the Universe is finite in extent, this question becomes impossible to answer, since – being part of the fabric of the Universe ourselves – we have no way of looking outside it. *AGu*



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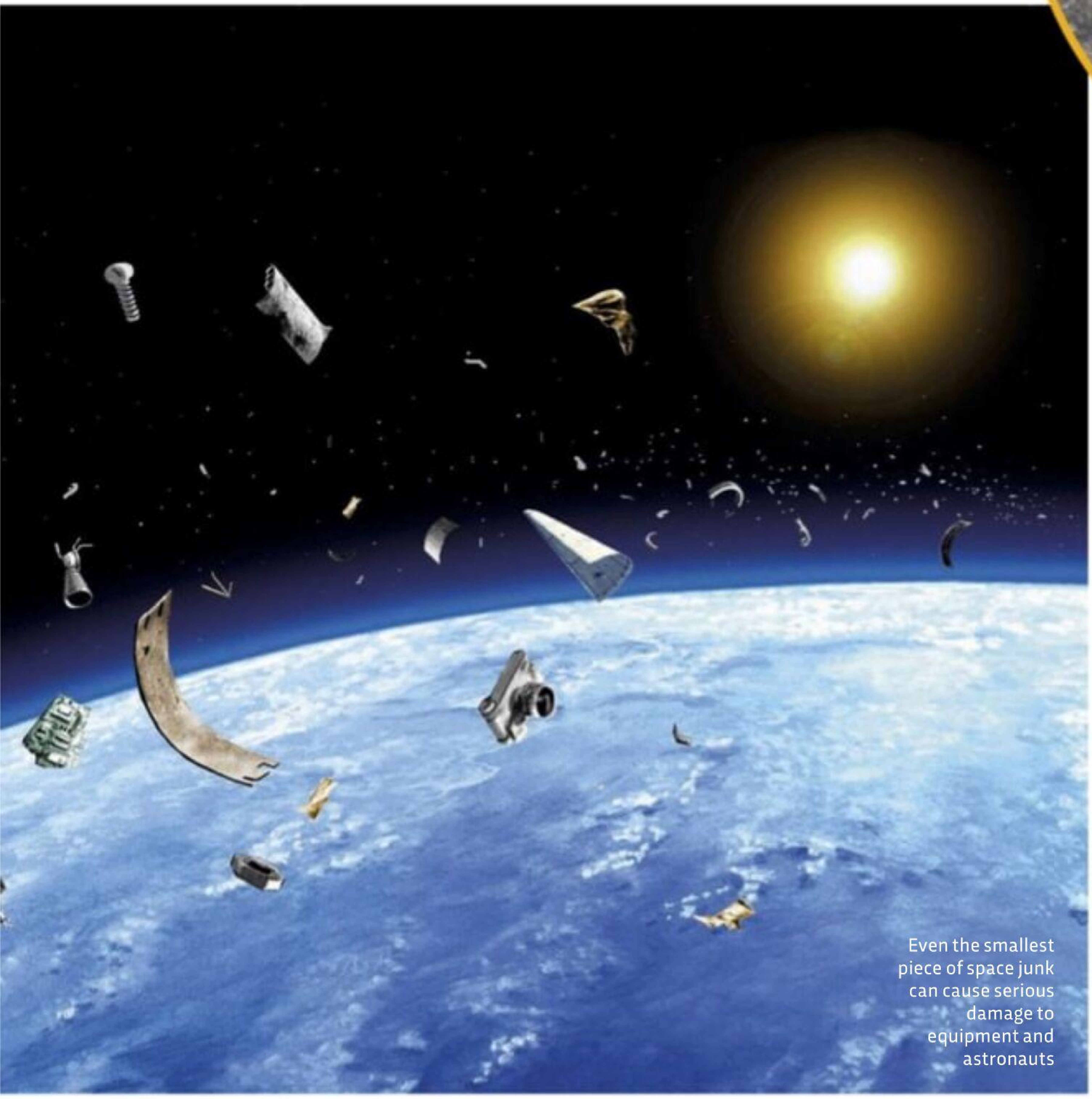


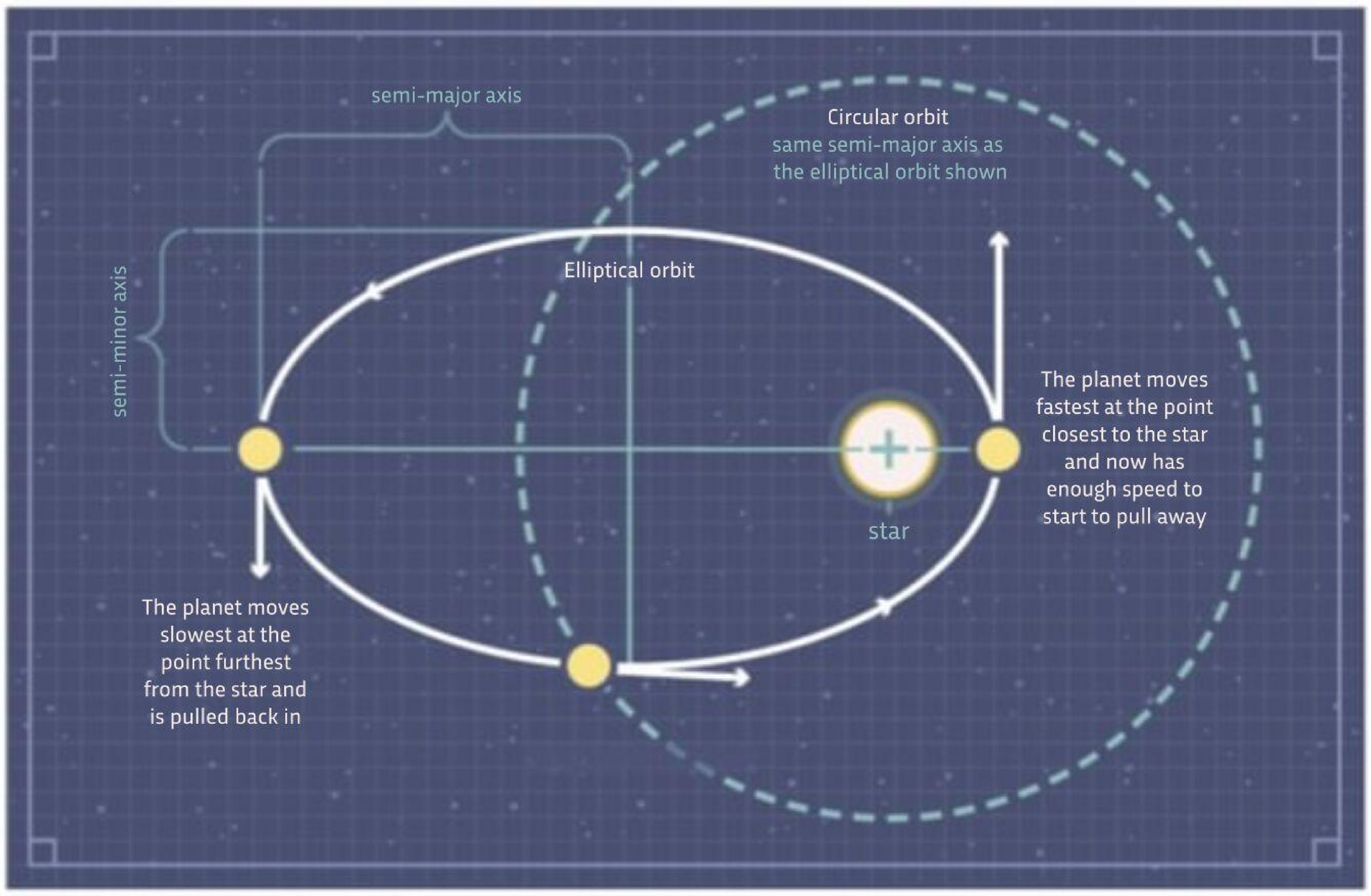
Even the smallest piece of space junk can cause serious damage to equipment and astronauts

COULD THERE BE MATERIALS ON OTHER PLANETS THAT WE DON'T HAVE ON EARTH?

Yes, because every so often, we get a delivery of such stuff from meteorites. Chemical analysis has so far identified around 300 minerals in these chunks of deep space debris, including around 40 that have only ever been seen in meteorites. One of the most intriguing materials was found in the Allende meteorite, which exploded over Mexico in 1969. After analysing samples of it, scientists in 2012 announced the discovery of a material that has not only never been seen on Earth, but wasn't even known to be possible. Named 'panguite' – after the giant Pan Gu who created the Earth in Chinese mythology – it consists of a bizarre mix of elements, including titanium, zirconium and scandium. ***RM***

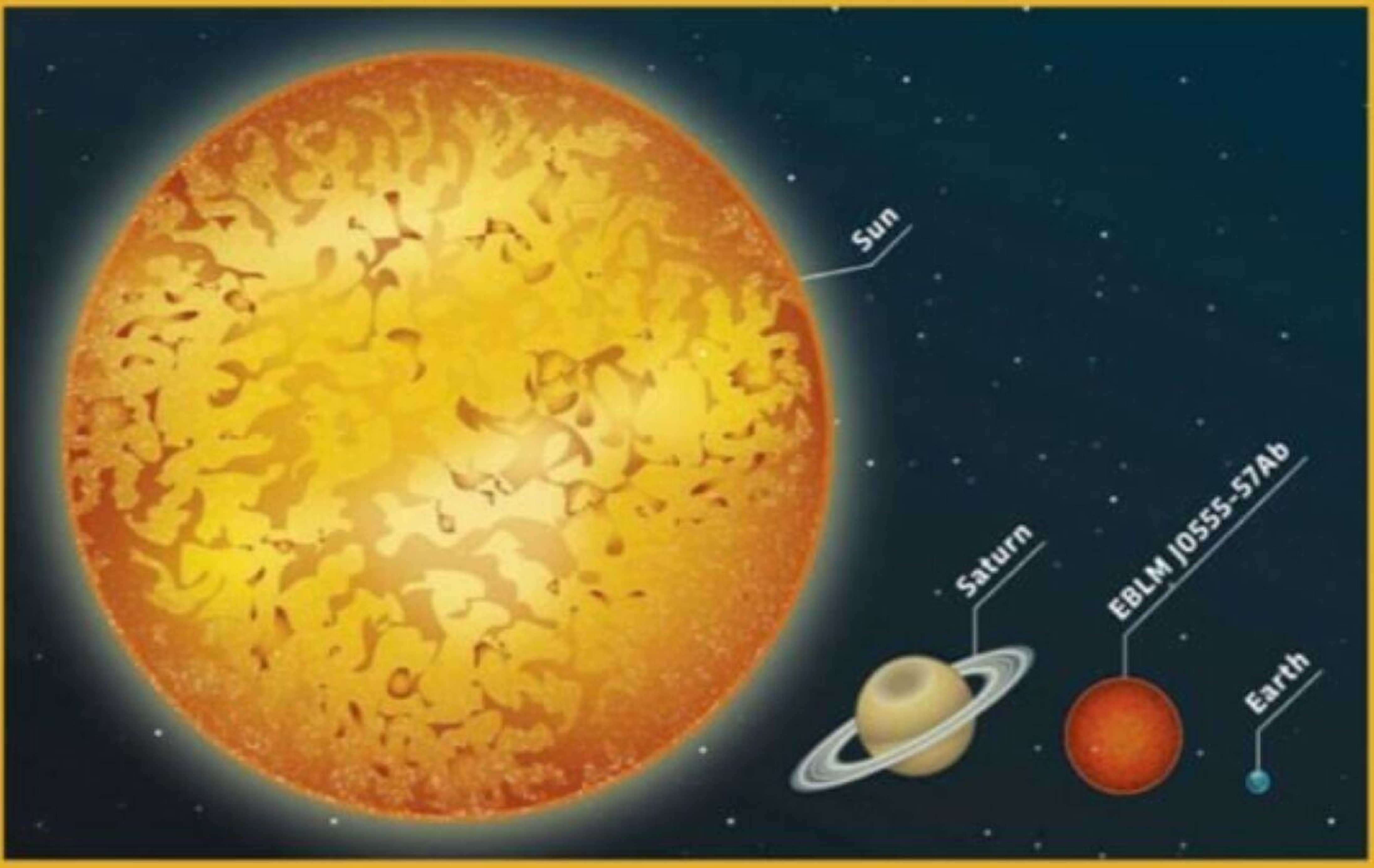
WHY DO OBJECTS IN SPACE FOLLOW ELLIPTICAL ORBITS?

The orbit of an object around its 'parent' is a balance between the force of gravity and the object's desire to move in a straight line. If the balance of forces is exact, then we get a circular orbit, but this is rarely the case. Usually, an orbiting object possesses just enough speed to pull away slightly from its parent (but not escape it). This slightly larger orbit causes the orbital speed to reduce, so eventually the object will be moving slow enough to be pulled back in. Hence, the object's distance from its parent oscillates, resulting in an elliptical orbit. ***AGu***


semi-major axis
Circular orbit
same semi-major axis as the elliptical orbit shown
semi-minor axis
Elliptical orbit
The planet moves fastest at the point closest to the star and now has enough speed to start to pull away
star
The planet moves slowest at the point furthest from the star and is pulled back in

WHAT IS THE SMALLEST KNOWN STAR IN THE UNIVERSE?

In 2017, an international team of astronomers announced the discovery of a so-called red dwarf star that's so small it barely functions as a star. Code-named EBLM J0555-57Ab and lying some 600 light-years away, it's similar in size to the planet Saturn. It has just enough mass to maintain the conditions needed to fuse together nuclei of hydrogen – the power source of stars like the Sun. Any smaller, and it would have become a brown dwarf – a 'failed star'. *RM*



COULD WE REUSE ANY ISS MODULES FOR A MARS MISSION?

It's extremely unlikely. The ISS components were not designed for the kinds of accelerations, or the amounts of radiation, experienced during interplanetary travel, and do not have adequate life support, power supply, fuel storage, docking systems or lander components. It would actually be much cheaper in the long run, and simpler, to build a Mars expedition vehicle from scratch. ***AGu***

WHERE IS THE CENTRE OF THE UNIVERSE?

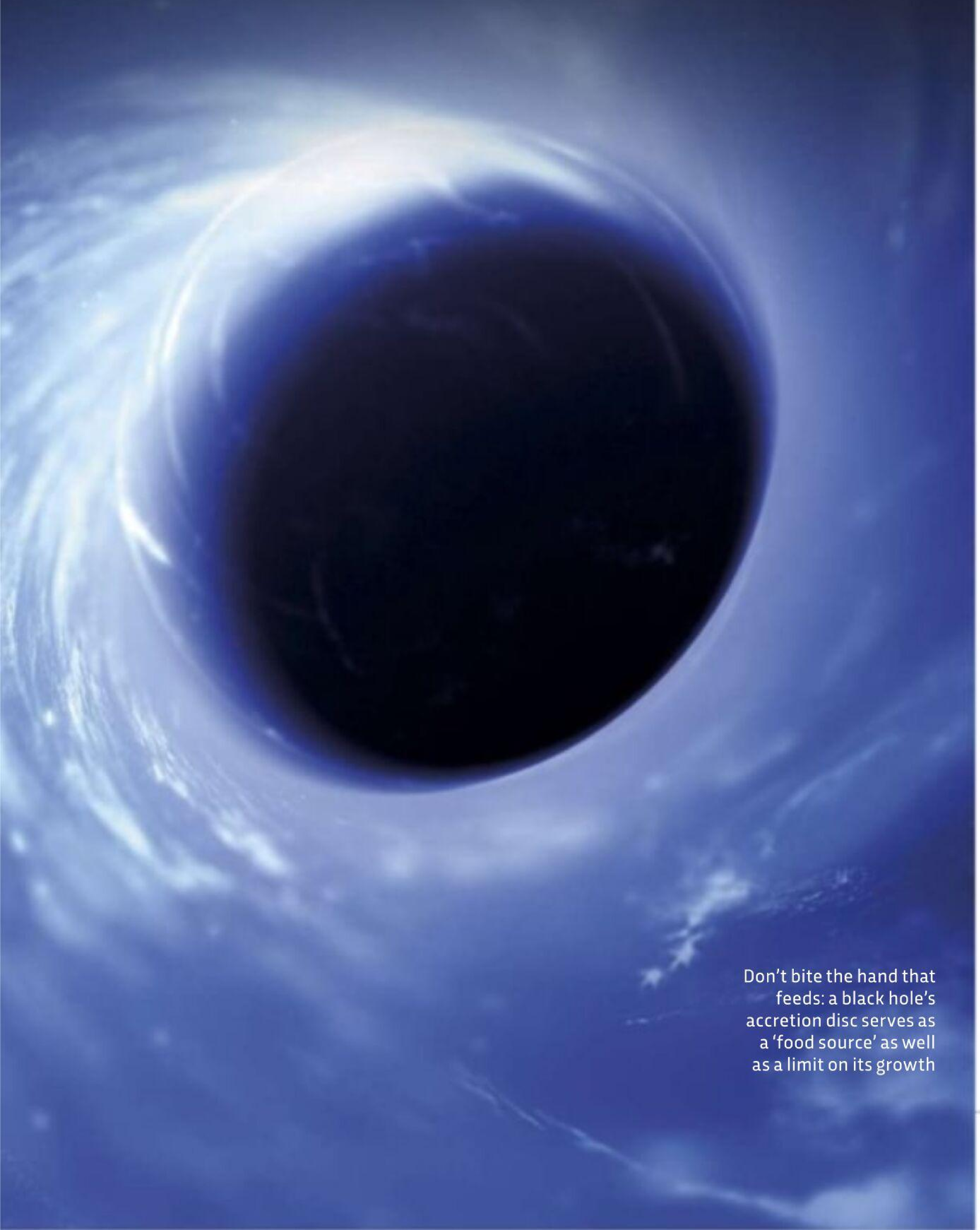
As the Universe may not have a physical edge, there is no sense in the idea of an 'absolute' position. Hence, it is meaningless to think of the 'centre' of the Universe; something of infinite extent has no 'centre'. Imagining the 'centre' as the point at which it began is also meaningless. The Big Bang happened everywhere at once and the Universe has been expanding ever since. Every point can be regarded as being at the 'centre' of this expansion. So, the centre of the Universe is nowhere, and everywhere! ***AGu***

100

The mass, in kilograms, of the UK-built RemoveDebris satellite. It's the largest satellite ever launched from the ISS and will trial methods to remove space junk

HOW BIG COULD A BLACK HOLE GET?

There is no theoretical upper limit to the mass of a black hole. However, astronomers have noted that the ultra-massive black holes (UMBHs) found in the cores of some galaxies never seem to exceed about 10 billion solar masses. This is exactly what we'd expect from the rate at which we know black holes grow, given the time that's elapsed since the Big Bang. Furthermore, recent studies suggest that UMBHs cannot physically grow much beyond this anyway, since they would then begin to disrupt the accretion discs that feed them, choking the source of new material. *AGu*



Don't bite the hand that feeds: a black hole's accretion disc serves as a 'food source' as well as a limit on its growth

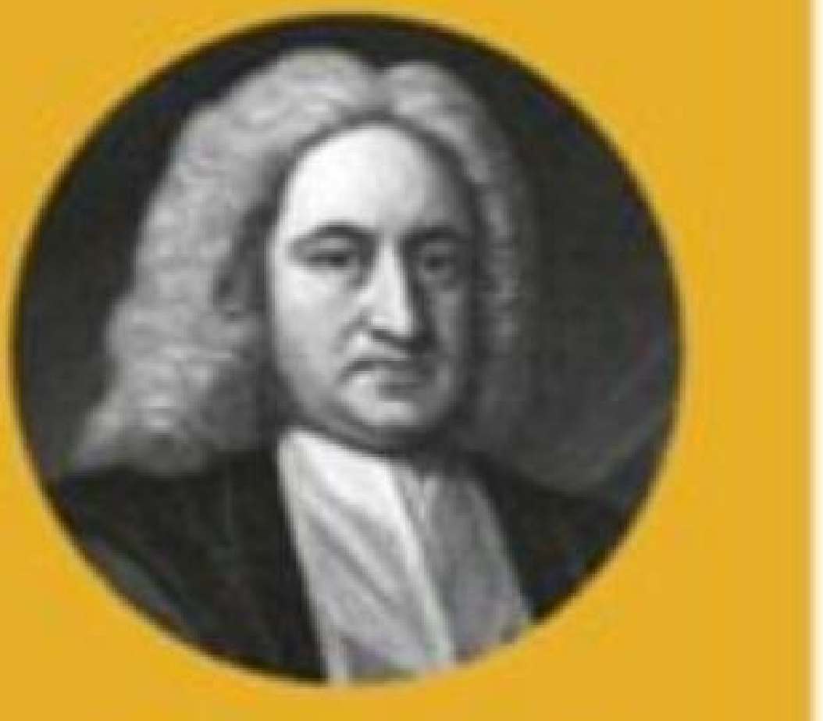
HOW DENSE IS THE UNIVERSE?

By making observations of fluctuations in the cosmic microwave background (the 'leftover' radiation from the Big Bang), astronomers have shown that the Universe is 'flat'. This means that its density appears to be close to the critical density, which is the density needed for gravity to just halt its expansion after an infinite time. The expansion rate we see today indicates that the critical density of the Universe is about 9×10^{-27} kg/m^3. This density, however, is the total density of both matter and energy. Observations have shown that ordinary matter accounts for 4.9 per cent of this density, while 26.8 per cent of it is due to dark matter, a form of matter not directly visible. The remaining 68.3 per cent is due to dark energy, a mysterious energy field causing the Universe's expansion to accelerate. So, ordinary matter has a density corresponding to about one proton for every four cubic metres of volume. The nature of dark matter and dark energy are not fully understood. ***AGu***

NASA, GETTY IMAGES X2

WHO REALLY DISCOVERED...?

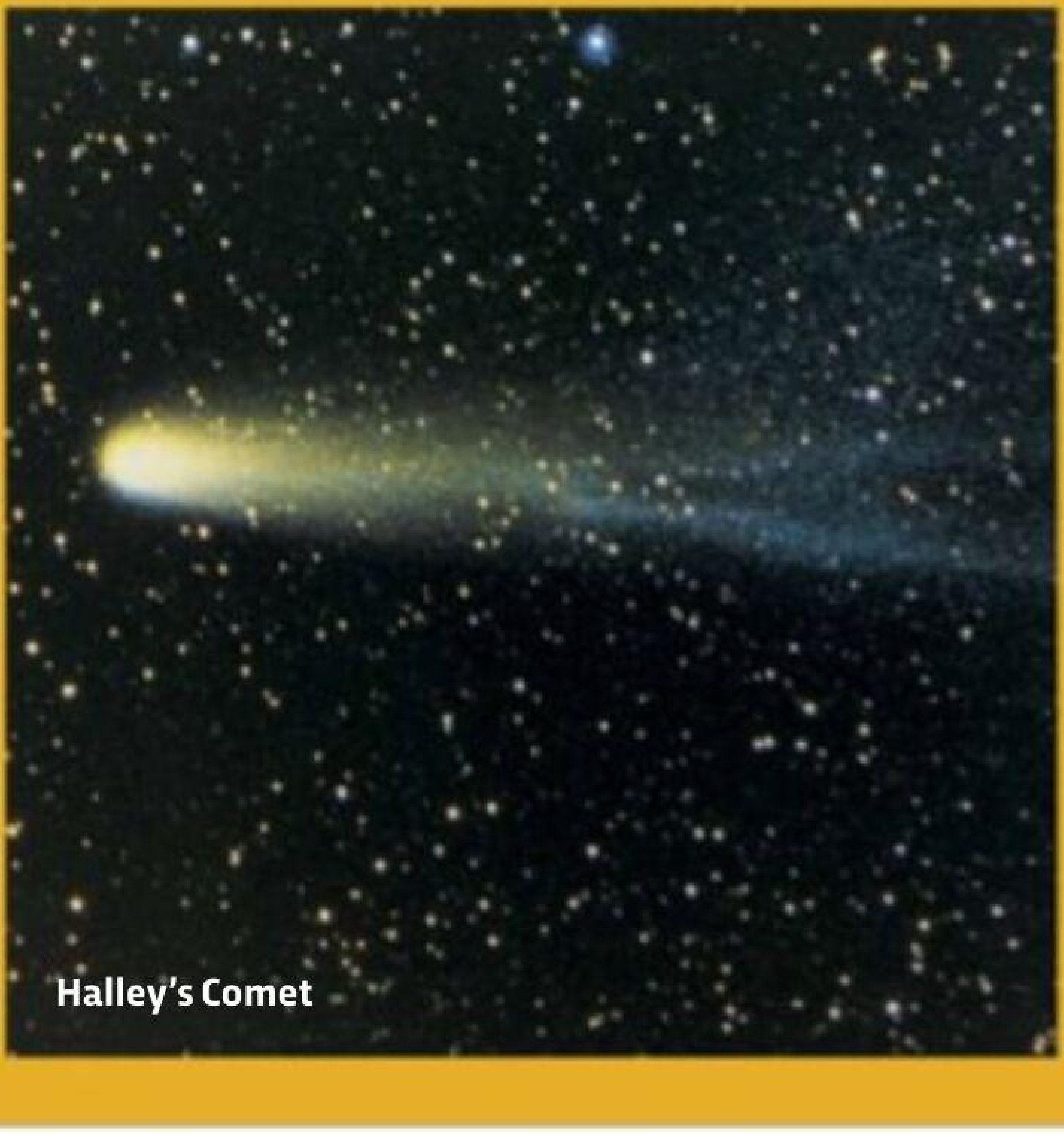
HALLEY'S COMET



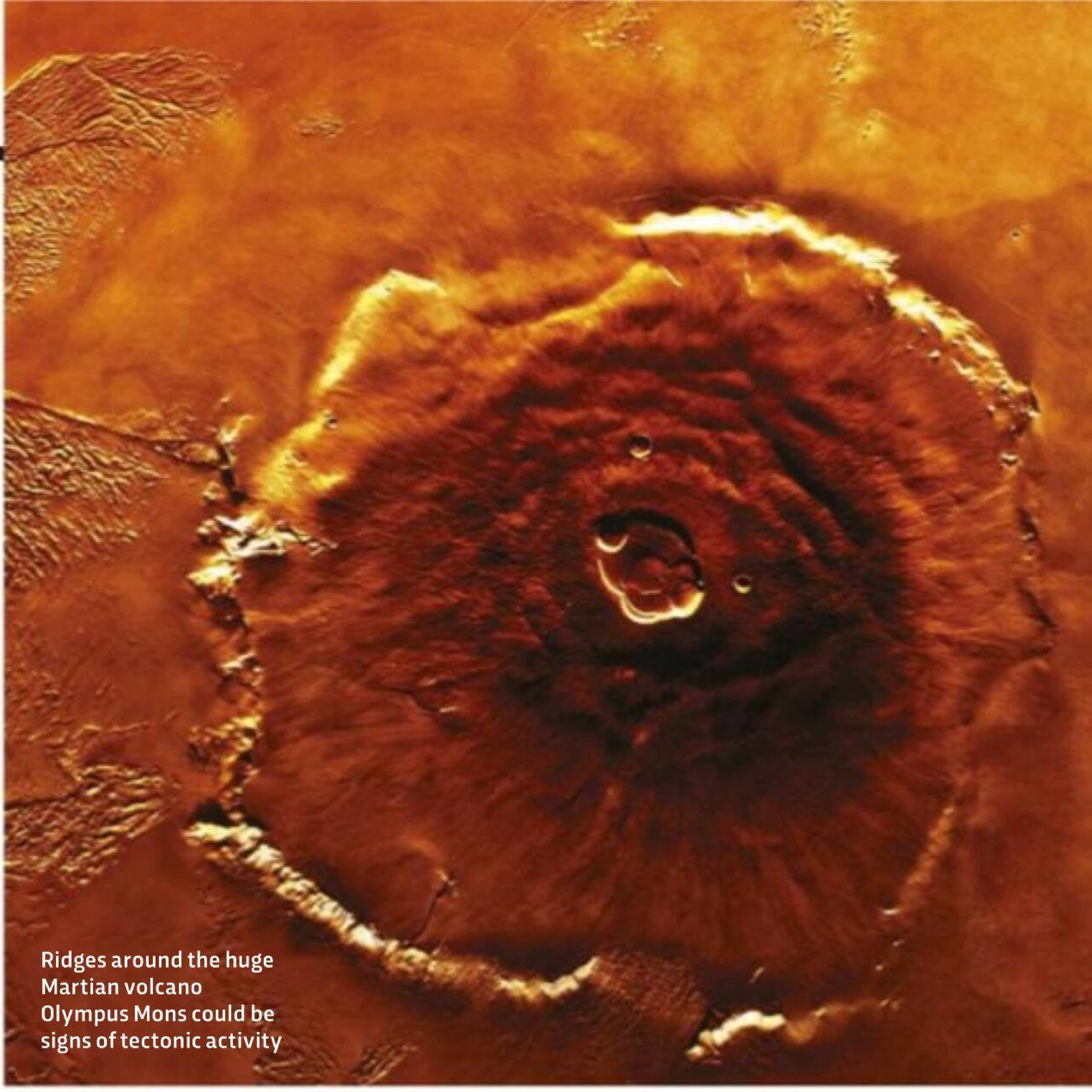
EDMOND HALLEY

CHINESE ASTRONOMERS

The most famous of all comets was certainly seen by the English astronomer and mathematician Edmond Halley when it flew round the Sun in 1682, but he did not discover it. The credit for that goes back at least another 2,000 years to 240 BC, when unknown Chinese astronomers noted what they called a 'broom star' appearing in the eastern sky in May of that year. Halley's claim to the name stems from his crucial discovery about the nature of the eponymous object. While studying a list of comet observations over the centuries, he noticed that the years 1531, 1607 and 1682 all featured the appearance of one of these supposedly capricious portents of doom. Was it just a coincidence that they were all about 76 years apart? Using Newton's then newly published law of gravity, he showed that they were all the same object, swinging round the Sun on a vast orbit. Halley predicted it would return in 1758, which it duly did. While he didn't live to see it, his calculations played a key role in showing that supposedly fickle natural phenomena can be understood through the power of science. *RM*



Halley's Comet



Ridges around the huge Martian volcano Olympus Mons could be signs of tectonic activity

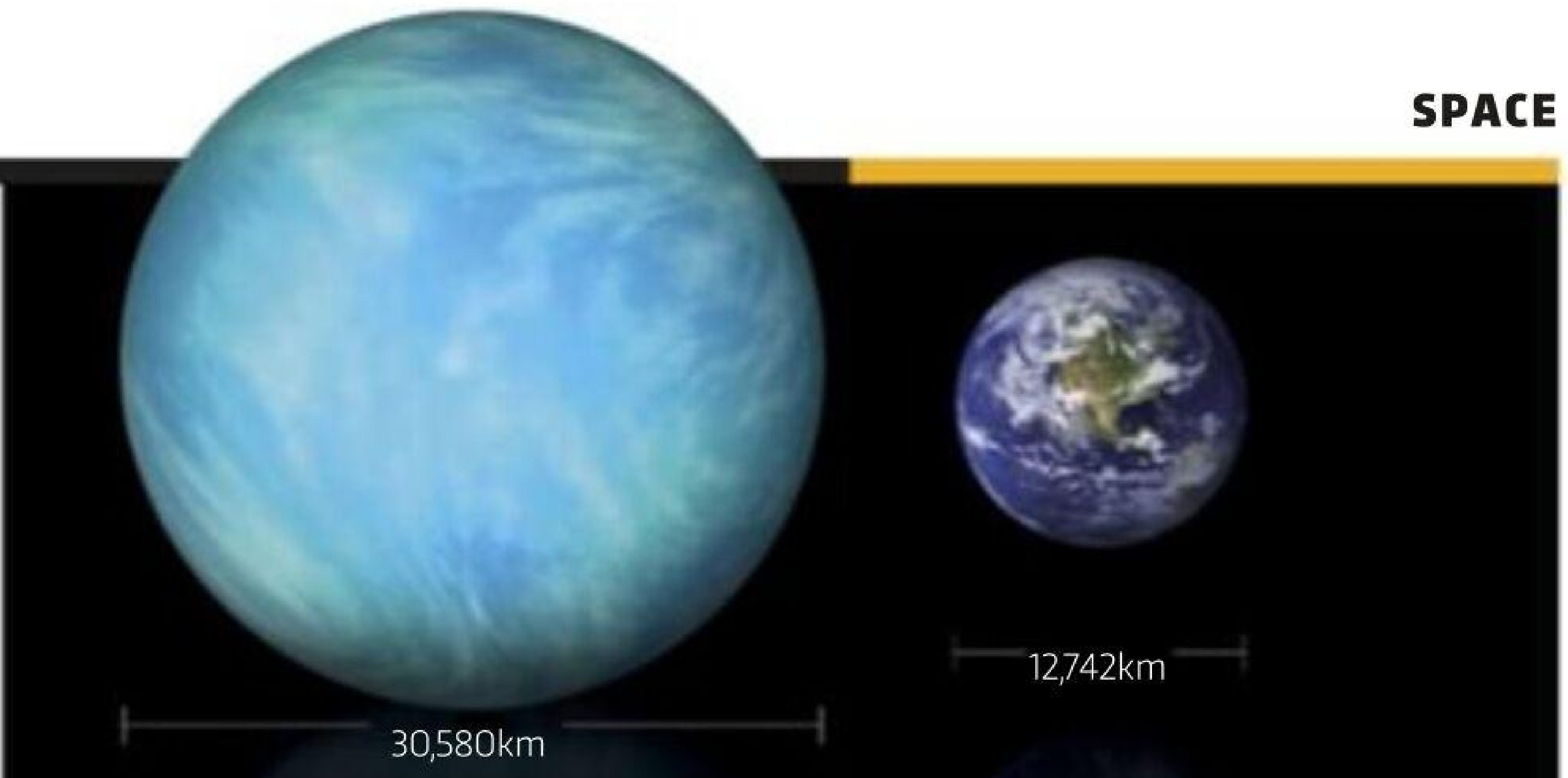
WHAT EFFECT DOES MICROGRAVITY HAVE ON MENSTRUATION?

Microgravity, such as that experienced on the International Space Station, has no effect on the menstrual cycle. In the 1960s, some experts warned against sending women into space over fears that menstruation and PMS could affect their ability to work. There were also concerns that blood might flow back into the body, pooling in the abdomen and causing peritonitis. The fears were unfounded. However, the issue of storing sanitary items, together with limited washing water, means that women in space tend to take oral contraceptive pills to prevent menstruation during their mission. ***ED***

GETTY IMAGES X5, NASA, PETER SUCHESKI

DO ANY OTHER PLANETS HAVE PLATE TECTONICS?

The idea that the Earth's fragmented crust drifts over the hot mantle beneath, often creating earthquakes and volcanoes, only gained widespread acceptance in the 1960s. Some planetary geologists believe that certain surface features on Mars, and the fact that it had active volcanoes during its earliest phase, indicate that the Red Planet may also have several crustal plates. Apart from this possibility, which is as yet unconfirmed, Earth appears to be unique in the Solar System in having plate tectonics, driven by huge convective loops of hot rock. This may be because the Earth's interior has remained warm enough for the material to flow easily, and possibly because the Earth's crust is relatively thin, and so more easily cracked to form plates. ***AGu***

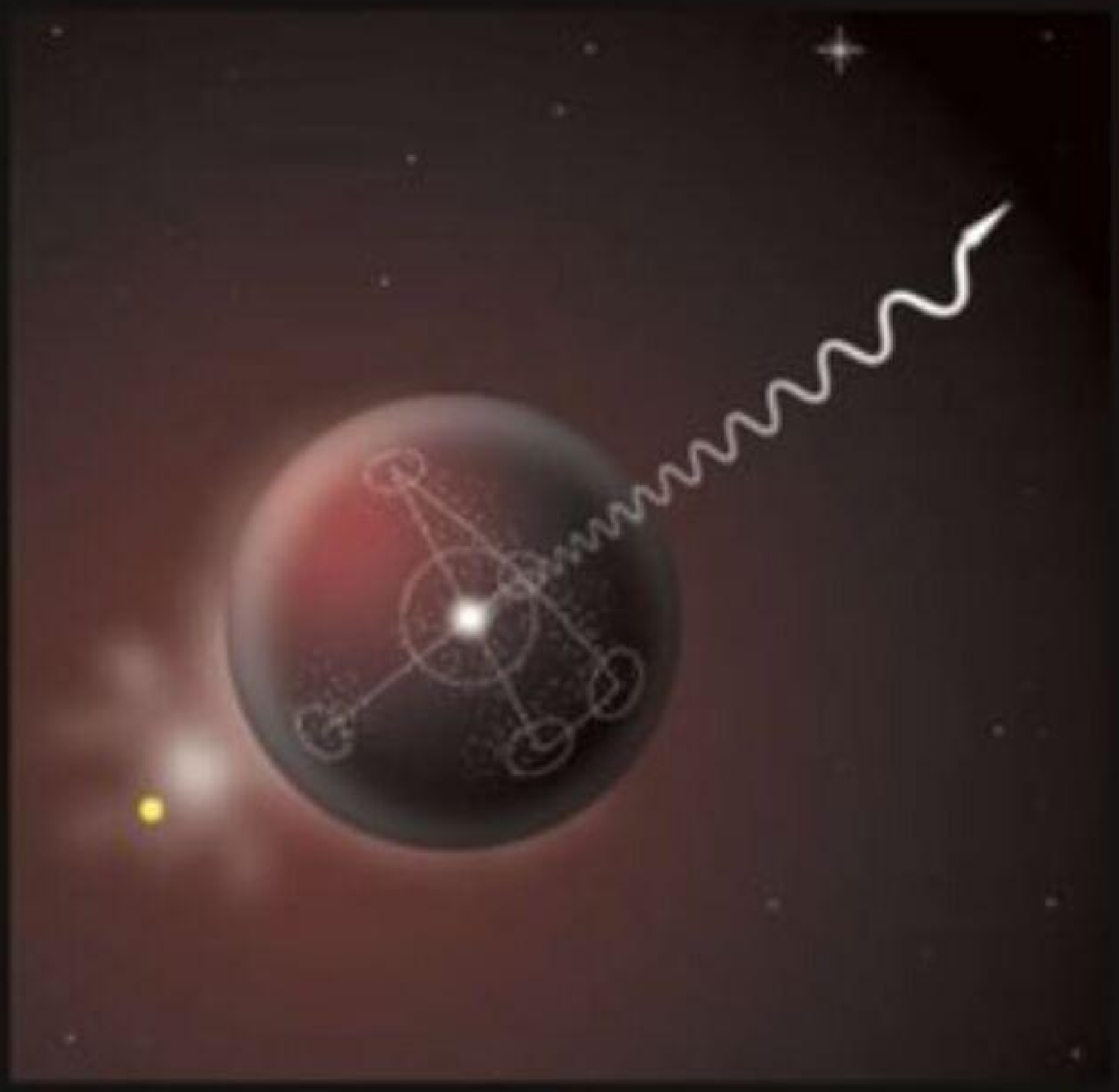


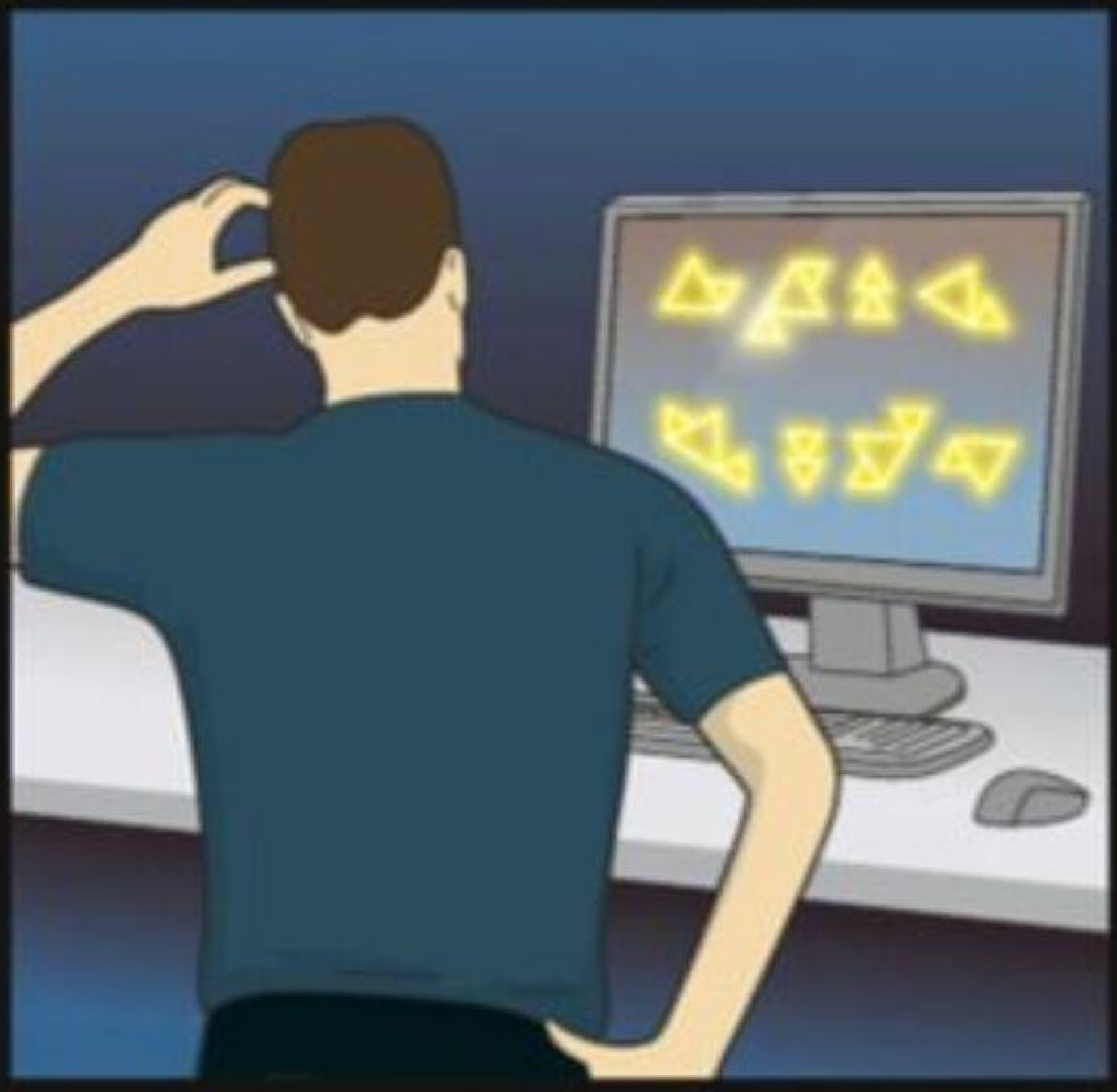
HOW DO SCIENTISTS WEIGH A PLANET?

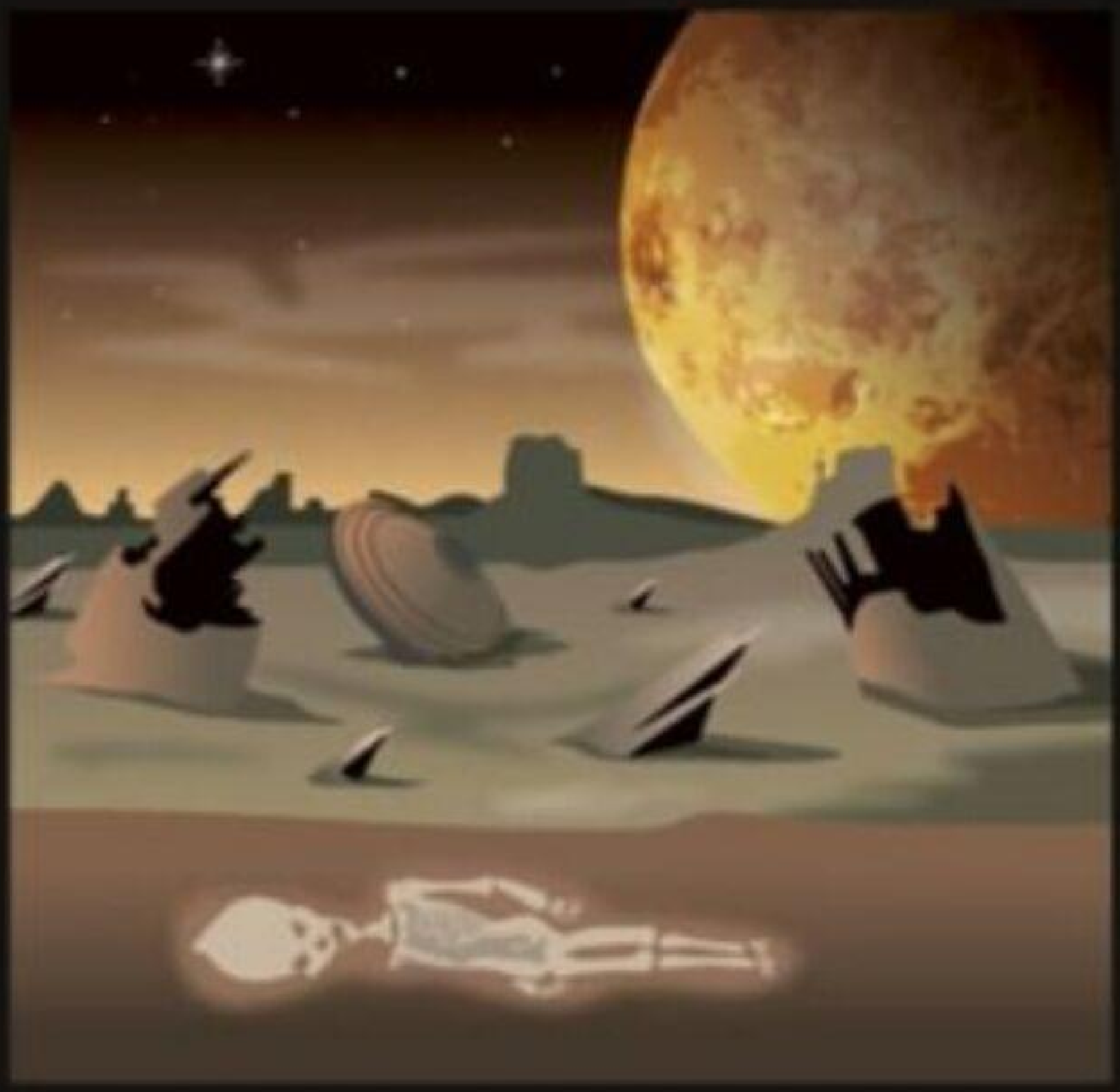
We can weigh a planet (or find its 'mass') by using Newton's Law of Gravitation. This law tells us that a planet exerts a gravitational pull that is proportional to its mass. If the planet has a moon, then this gravitational pull must be balanced by the centripetal force that keeps the moon in orbit. In this case we only need to measure the moon's orbital period and the distance between the planet and its moon to reveal the planet's mass. For planets without moons, we can still use their effect on other planets to infer their masses. ***AGu***

THE THOUGHT EXPERIMENT

WHAT WOULD HAPPEN IF ALIENS CONTACTED US?







1. COULD WE DECODE IT?

Humans have only been transmitting radio signals for around 80 years, and already we are phasing out analogue transmission systems such as AM and FM in favour of digital signals. These are much easier to detect – but only if you know the encoding system. Without this key piece of information, any transmission from an alien civilisation would just sound like background static.

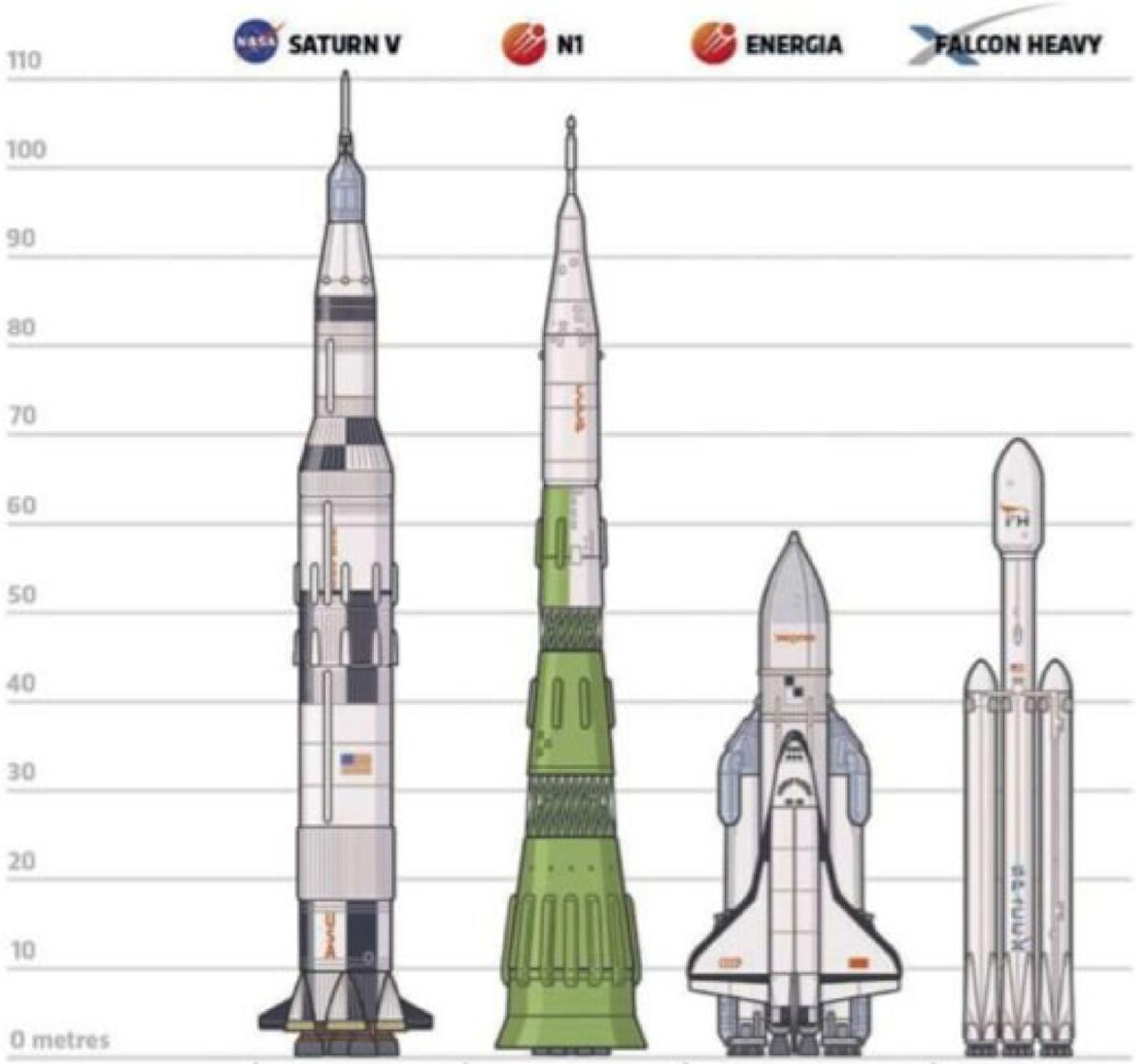
2. COULD WE UNDERSTAND IT?

In 1974, the Arecibo telescope broadcast a 23 x 73 pixel image at the M13 star cluster. Although it contains details of our counting system, DNA structure and location, it's so cryptic that even other humans probably wouldn't be able to decipher it. An alien message might have such an abstract set of priorities and assumptions that we'd never understand what they were trying to say.

3. ARE THEY STILL THERE?

Even if we received and understood a message, its senders would probably be long gone. A 2018 study at the University of California, Santa Cruz, found that if civilisations last fewer than 100,000 years, the odds of detecting a signal while the transmitting civilisation still exists are almost nil. So there's not much hope of sending (or receiving) a reply.

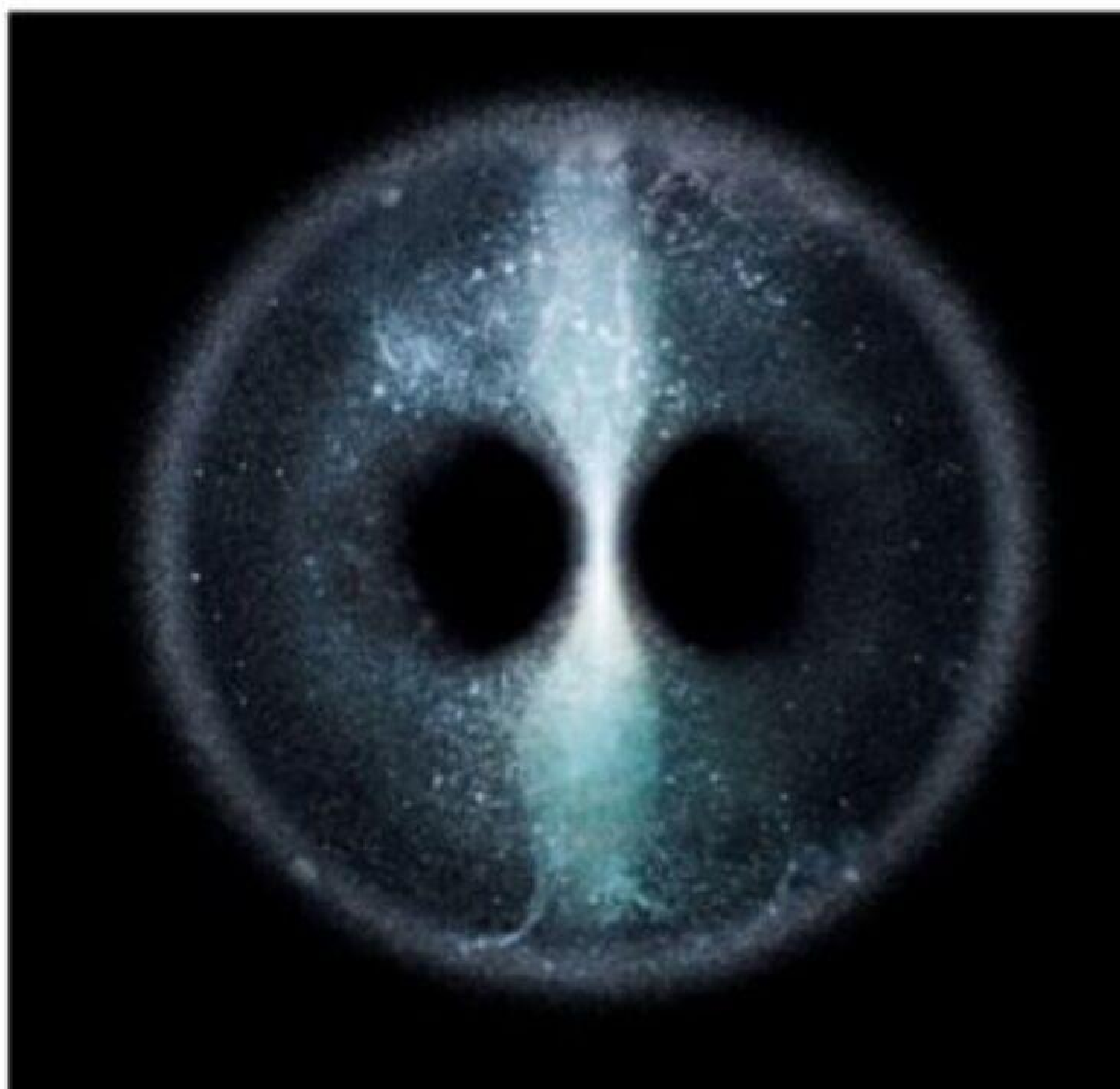
HOW DOES SPACEX'S FALCON HEAVY COMPARE TO OTHER ROCKETS?



	SATURN V	N1	ENERGIA	FALCON HEAVY
Years in service	1967 - 1973	1969 - 1972	1987 - 1988	2015 -
Launch cost	$1200m	$1375m	$600m	$150m
Launch success rate	12/13	0/4	2/2	1/1
Payload to LEO (Low Earth Orbit)	140,000kg	95,000kg	88,000kg	63,000kg
Payload to TLI (Trans-Lunar Injection)	48,600kg	25,500kg	20,000kg	16,000kg

ARE THERE ANY STARS BETWEEN GALAXIES?

Although stars cannot form in the voids between galaxies (since the density of matter is far too low), there are in fact large numbers of 'intergalactic stars'. It has been estimated, for example, that 10 per cent of the mass of the Virgo galaxy cluster is in the form of these stellar interlopers. How they got there is still a matter of debate, but there are two possible processes, both resulting from gravitational interactions. First, stars can be expelled from their parent galaxy if it collides, merges or passes close to another galaxy. Second, if a star has a close encounter with a supermassive black hole (usually residing at the galactic centre), it can be accelerated to extremely high velocities, eventually leaving its parent galaxy altogether. ***AGu***

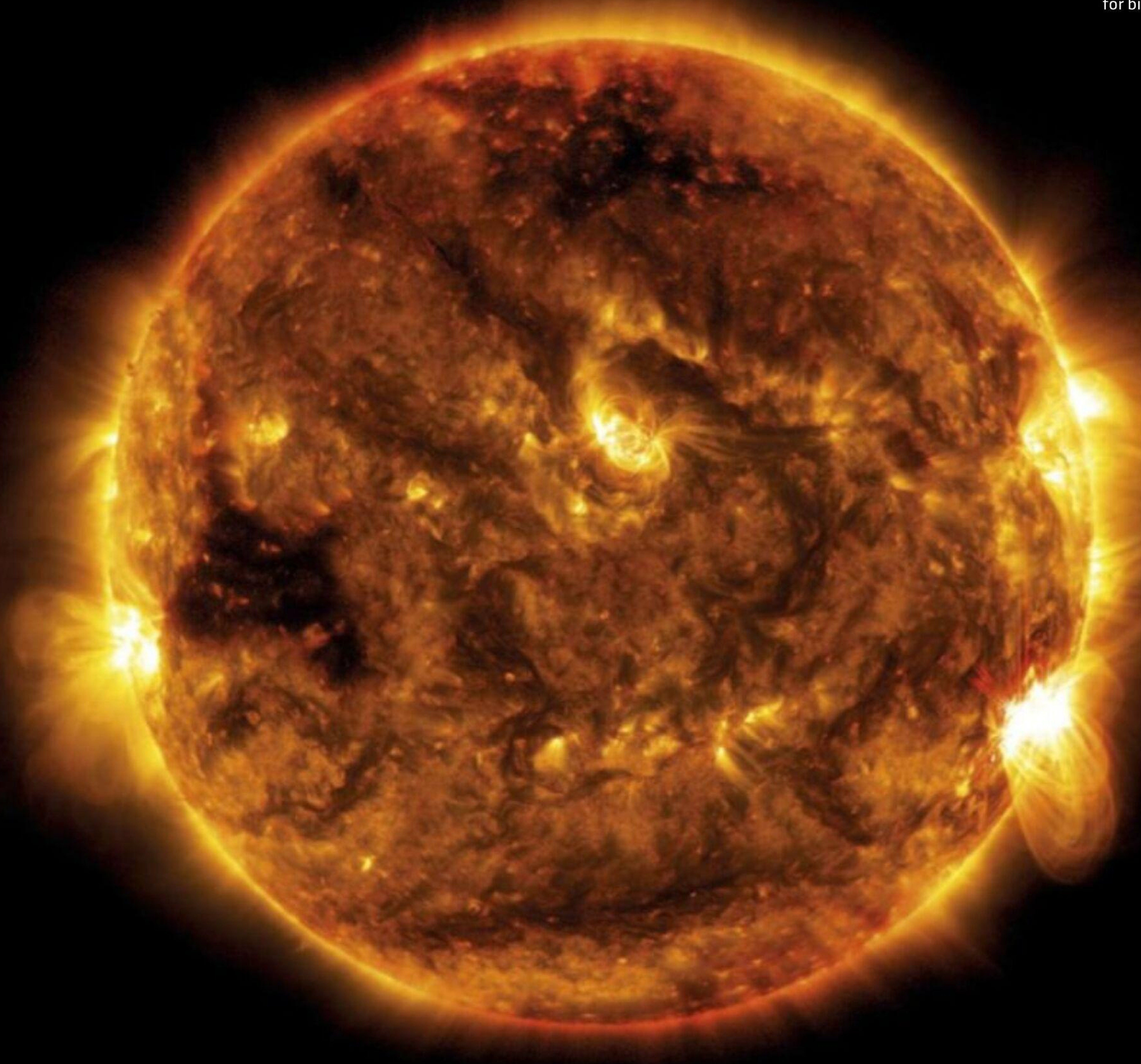


The Oort Cloud is thought to surround our Solar System in a sphere-like halo

HAS ANY OTHER STAR COME CLOSE TO OUR SOLAR SYSTEM?

Stars may seem fixed in position, but they move through space too: their vast distance means it takes a long time for their shifts to be seen. Countless stars have approached our Solar System over its history. While there's no evidence of a collision, the orbits of the outer planets are thought to have changed during that time. It's possible that this was due to gravitational jostling among the planets, but a stellar intruder can't be ruled out. A 'near miss' with a star could have devastating consequences. Far beyond the known planets lies the Oort Cloud, a vast collection of icy debris and comets. A star passing even a light-year or so away could stir these up, hurling cosmic missiles at the planets. To assess the risk, astronomers at the Max Planck Institute in Germany, analysed the movement of over seven million stars. Fortunately, they found just one – Gliese 710 – likely to disturb the Oort Cloud over the next million years or so. ***RM***

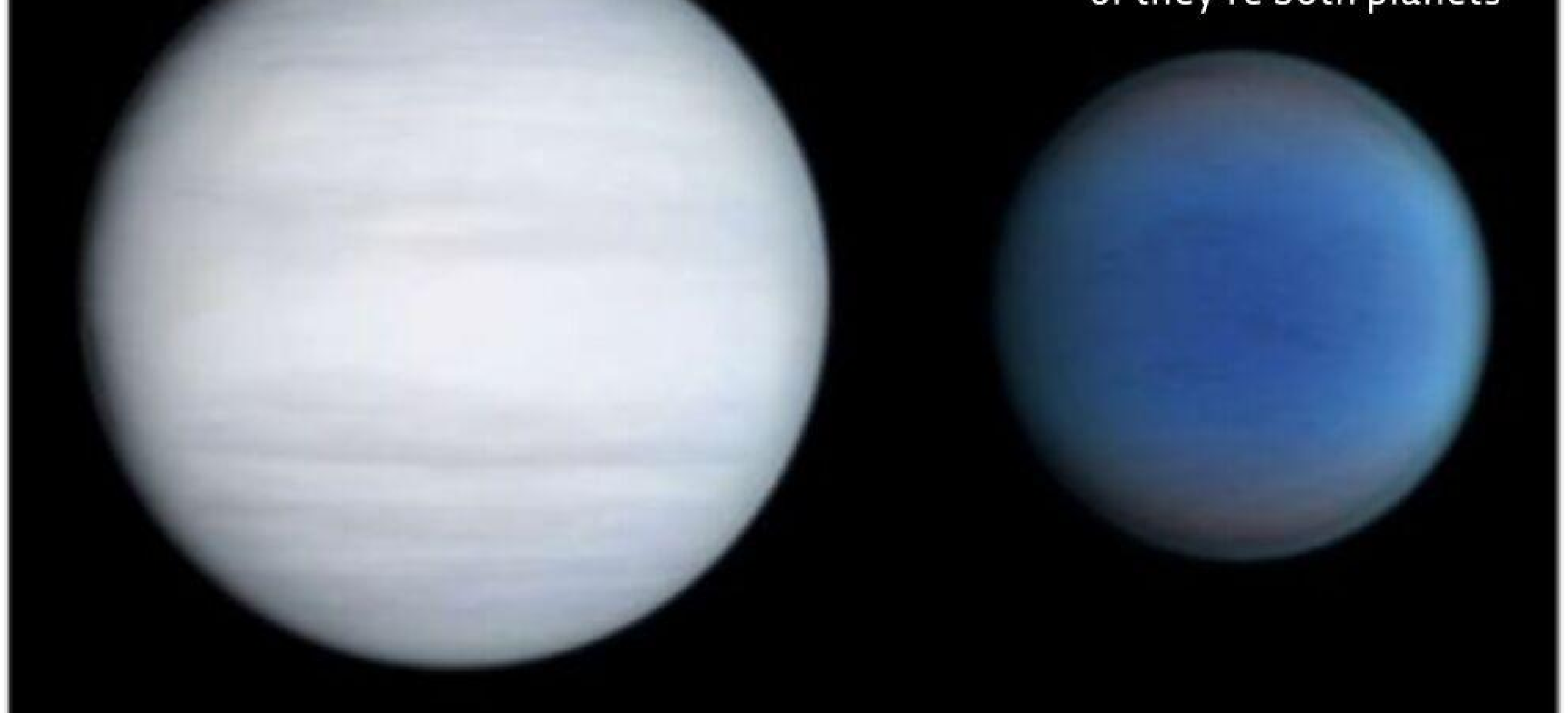
NASA, SCIENCE PHOTO LIBRARY, RAJA LOCKEY



Nuclear fusion on a truly grand scale has kept the Sun burning for billions of years

WHY DOESN'T THE SUN FUSE ALL ITS HYDROGEN AT ONCE AND EXPLODE LIKE AN H-BOMB?

The Sun is powered by the energy released when the nuclei of its hydrogen atoms slam together so hard they fuse together. As these nuclei are protons with the same positive charge, they repel each other, so it takes incredibly high temperatures in excess of around 15,000,000°C to persuade them to fuse together. But such conditions exist only in the Sun's intensely hot, dense core, which makes up barely one per cent of its total volume. ***RM***



If two orbiting bodies are made of gas it can be difficult to determine if one's a moon or they're both planets

COULD A GAS MOON EXIST?

Just like gas planets, a gas moon would need to be a lot bigger than its rocky counterparts – if it were too small then it wouldn't have enough gravity to hold on to large amounts of light gases such as hydrogen and helium. However, this means that a 'gas moon' would likely be of comparable size to its parent planet, and so would more appropriately be called a 'binary planet'. Such gaseous binary planets are possible, but probably extremely rare because planet formation would usually result in the two objects merging or deflecting each other to separate orbits. So we haven't spotted one yet! ***AGu***

HOW LONG WOULD IT TAKE AN ASTRONAUT TO WALK AROUND THE MOON?

The Apollo astronauts managed a walking speed of about 2.2km/h, which is around half of the typical speed on Earth. This is partly because the Moon's lower gravity gives you much less traction on the ground, but the Apollo spacesuits were never really designed with long-distance hikes in mind.

A 2014 NASA study looked at the theoretical maximum walking speed on the Moon, finding that you could walk at 5km/h before you would need to break into a loping run. At this speed, you would travel the 10,900km circumference of the Moon in 91 days of non-stop walking. ***LV***

HOW LARGE A TELESCOPE WAS NEEDED TO IMAGE AN EXOPLANET?

The first-ever image of a planet beyond the Solar System was taken in 2005 by astronomers using the European Southern Observatory's Very Large Telescope (VLT) in Chile. Known as 2M1207b, the planet is about 1.5 times bigger than Jupiter and around 170 light-years away. It was detected using one of the VLT's four gigantic telescopes, whose light-gathering mirrors are an impressive 8.2 metres across. *RM*

GETTY IMAGES, NASA X2, SCIENCE PHOTO LIBRARY

WHO REALLY DISCOVERED…?

BLACK HOLES

LOUISE WEBSTER

PAUL MURDIN

While their enigmatic name was first coined in 1967, the idea of objects whose gravity is so intense not even light can escape them is far older. In 1783, an English cleric and amateur scientist named John Michell showed that Newton's law of gravity suggested such objects could exist. But Michell went further, suggesting that despite being invisible, such objects might reveal themselves if they happened to have a star in orbit about them.

He proved to be amazingly prescient in both respects. During the 1930s, theorists using Einstein's more sophisticated theory of gravity, known as General Relativity, showed that sufficiently massive stars could collapse under their own gravity at the end of their life, and transform into black holes (ironically, even Einstein never accepted that such strange objects could really exist).

Michell's second claim was confirmed in the early 1970s. Astronomers Louise Webster and Paul Murdin at the Royal Greenwich Observatory and Thomas Bolton, a student at the University of Toronto, independently announced the discovery of a massive but invisible object in orbit around a blue star over 6,000 light-years away. The object, an intense X-ray source codenamed Cygnus X-1, is now regarded as the first black hole to be identified. *RM*

Cygnus X-1

DOES THE SUN MAKE A SOUND?

The Sun does indeed generate sound, in the form of pressure waves. These are produced by huge pockets of hot gas that rise from deep within the Sun, travelling at hundreds of thousands of miles per hour to eventually break through the solar surface. As a result, the Sun's atmosphere is seething like a pan of boiling water. The characteristics of sound waves, such as their speed and amplitude, depend on the material they pass through, so they can be used to study the Sun's deep interior. Unfortunately, though, the wavelength of these waves is measured in hundreds of miles, and so they're far outside the range of human hearing. ***AGu***

COULD WE STOP AN ASTEROID FROM COLLIDING WITH EARTH?

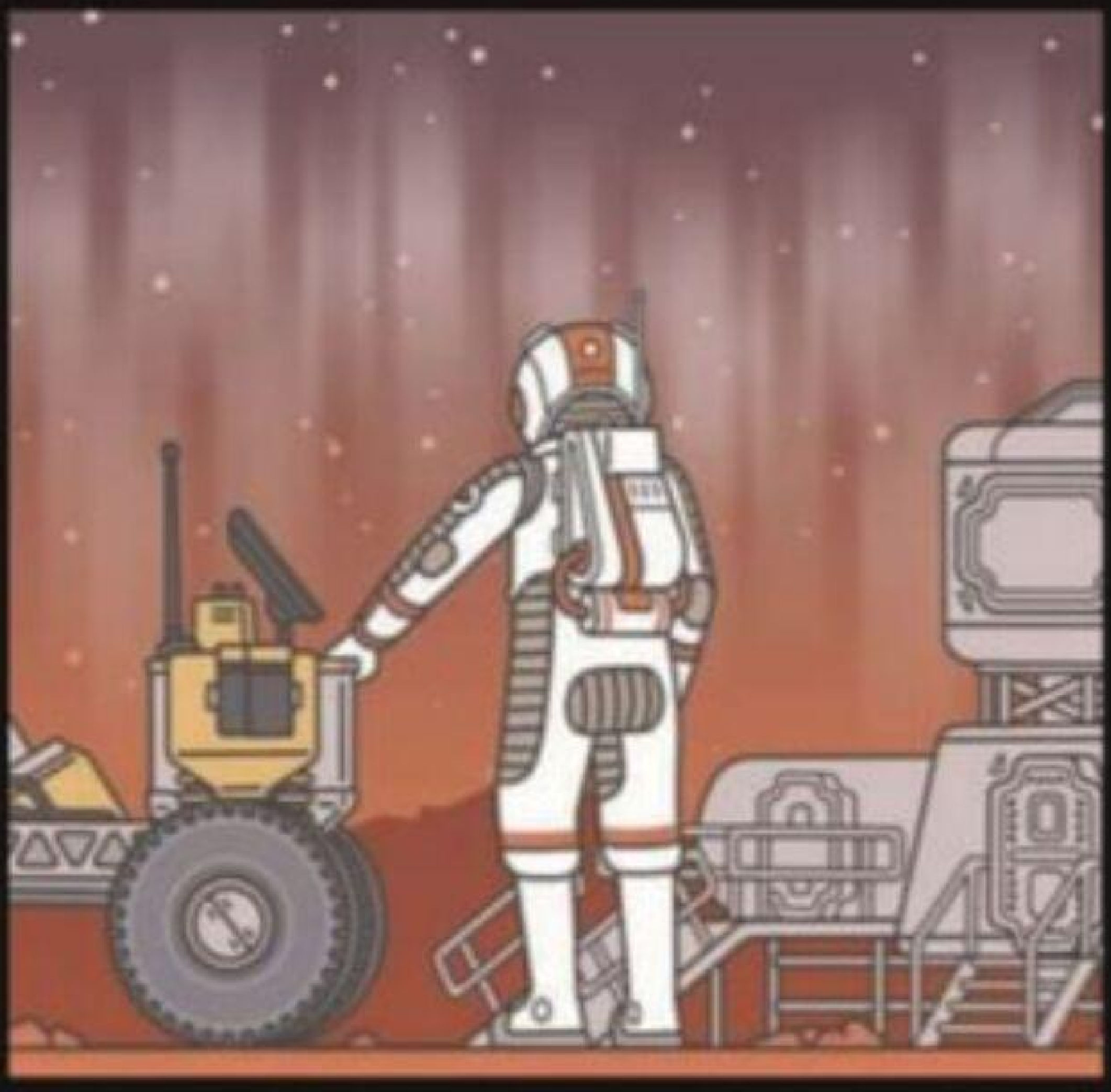
It is certainly possible, but would be a difficult and expensive task. The key would be in deflecting the asteroid away from its collision course with Earth rather than shattering it into equally dangerous debris. This could be done by impacting it with a non-destructive projectile, simply tugging the asteroid into a different orbit with a nearby high-mass spacecraft, ablating the asteroid's surface with a high-power laser (or a nearby nuclear explosion), or by placing small rockets on the asteroid's surface. All of these techniques would require at least five years to achieve, which is why early warning of potential asteroid impacts is vitally important. ***AGu***

THE THOUGHT EXPERIMENT

WHAT WOULD LIVING ON MARS DO TO MY BODY?

1. LOWER GRAVITY

The effects of zero gravity have been studied on the International Space Station, but the long-term impact of low gravity is unknown. An hour in a special gym each day might be enough to stave off muscle wasting and bone loss. But reduced gravity also lowers red blood cell counts and compromises your immune system, and a treadmill won't help with that.



2. RADIATION

The surface radiation on Mars is 0.67mSv per day, which is the equivalent to a daily hip X-ray. This radiation is mostly in the form of galactic cosmic rays. Martian soil could be used to shield a Mars base from them, but the covering would need to be five metres thick. Even for a three-year round trip to Mars, studies predict a 10 per cent chance of developing a fatal cancer.

3. TOXIC SOIL

Martian topsoil is full of highly reactive perchlorates, formed by UV rays. Some of this dust will be tracked into the Mars base and be inhaled or ingested. Perchlorate poisoning is reversible, but on Mars you'll be constantly exposed. Just 25 parts per billion in drinking water will suppress thyroid function and raise blood pressure. Higher doses cause lung damage.

WHAT DO THE OTHER PLANETS SMELL LIKE?

Astronomers recently found that the atmosphere of Uranus has high levels of hydrogen sulphide, a compound that smells like rotten eggs. The only first-hand account of the smell of another celestial body came from the Apollo astronauts, who claimed that Moon dust smelt like spent gunpowder. Mercury has a very sparse atmosphere and so would not have much of a smell at all. Venus and Mars, much like Uranus, have substantial quantities of eggy hydrogen sulphide. For Jupiter, the smell would depend on where you were in the atmosphere. Some regions have high concentrations of ammonia (which smells like cleaning fluid), others hydrogen sulphide (eggs) and elsewhere hydrogen cyanide (bitter almonds). Saturn and Neptune probably don't have much of a smell because they're composed chiefly of the odourless gases hydrogen and helium. ***AGu***

2.647

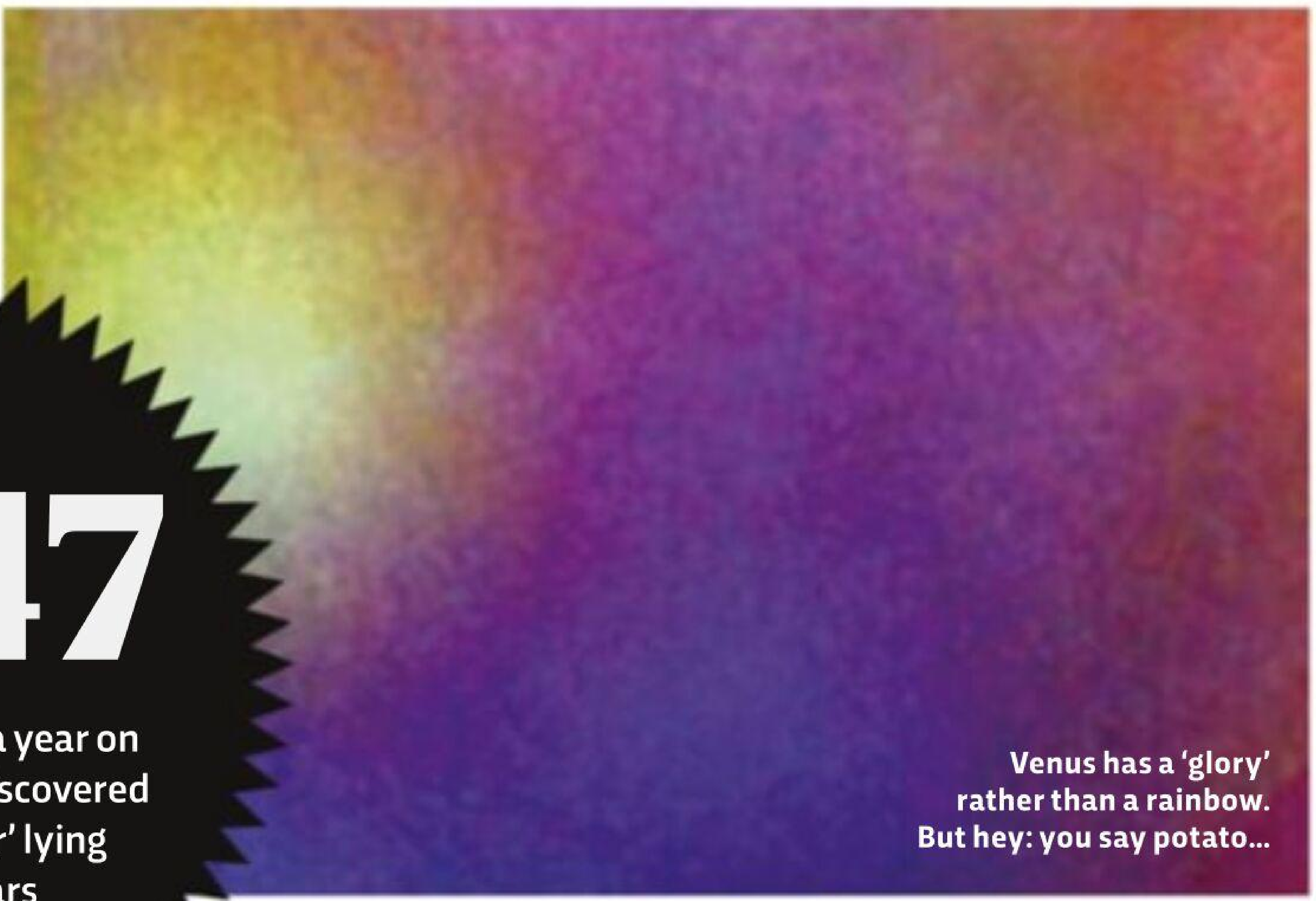
Length, in Earth days, of a year on the exoplanet NGTS-1b. Discovered in 2017, it's a 'hot Jupiter' lying some 600 light-years from Earth

IF THE UNIVERSE IS EXPANDING, WHY IS THE ANDROMEDA GALAXY ON COURSE TO COLLIDE WITH THE MILKY WAY?

The expansion of the Universe is a large-scale phenomenon: in general, the further away a galaxy is, the faster it recedes from us. But over small regions of space, this expansion is negligible compared to the motion of individual galaxies. The Andromeda and Milky Way galaxies are sufficiently large and close to create a gravitational force that overcomes the general expansion and pulls them together. But don't worry, the collision won't happen for another four billion years. ***AGu***

IS IT TRUE THAT VENUS HAS ITS OWN FORM OF RAINBOW?

Venus has an optical phenomenon called a 'glory', which – like a rainbow – forms when sunlight falls on cloud droplets. However, glories are caused by the interference of light waves within droplets, whereas rainbows are caused by the reflection, refraction and dispersion of light. Unlike the broad arc of a rainbow, a glory is typically seen as a series of coloured concentric rings. In 2011, a Venusian glory was observed by ESA's Venus Express probe, probably caused by sunlight interacting with the sulphuric acid/ferric chloride droplets in the planet's atmosphere. *AGu*



Venus has a 'glory' rather than a rainbow. But hey: you say potato...

NASA, GETTY IMAGES, PETER SUCHESKI

LG

EYE OPENER

CES, LAS VEGAS

What is this?

This installation greeted visitors to LG Electronics's booth at the 2019 CES convention. The exhibit, dubbed the 'Massive Curve of Nature' and intended to be a showcase for LG's flexible OLED technology, featured 260 curved OLED (organic light-emitting diode) screens arranged in a series of contours from the floor to the ceiling to cover the attendees' fields of view. During the convention, the screens displayed a two-minute video loop of skyscapes, waterfalls, deserts, rainforests and nebulae.

Unlike in LCD and LED screens, the pixels in OLED displays are self-illuminating, so they don't need a backlight layer and can be made thinner and more flexible.

GETTY

VISIT US FOR MORE AMAZING IMAGES:

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WHICH PLANE HAS THE BIGGEST WINGSPAN?

The passenger plane with the biggest wingspan is the airbus A380 – a monster double-decker plane that carries 550 people, with a wingspan of 80m. But the overall plane with the biggest wingspan is an aircraft that carries no passengers at all. Paul Allen, co-founder of Microsoft and one of the world's richest men, has helped create the Stratolaunch – an aircraft with six 747 jet engines and twin fuselages (the flight crew go in the fuselage on the right while instrumentation is carried in the one on the left). The Stratolaunch has been built to carry rockets high into the atmosphere to make launching satellites cheaper and more reliable. Its wingspan is an immense 117m and the aircraft made its maiden flight on 13 April 2019. *PB*

Stratolaunch has the biggest wingspan of any aeroplane and will be used to propel satellites into orbit

TECHNOLOGY

PLANES, PLASTIC MONEY, ELECTRIC CARS, COMPUTERS, ROBOTS, ARTIFICIAL INTELLIGENCE, GPS, TOILETS AND THE INTERNET…

DOES A USB DRIVE GET HEAVIER AS YOU STORE MORE FILES ON IT?

Believe it or not, they get lighter. USB drives use Flash memory, which means the ones and zeros of your data are stored on transistors. A zero is set by charging the float gate of the transistor, and a one is set by removing the charge. To charge it, we add electrons, and the mass of each electron is 0.000000000000000000000000091g. This means that an empty USB drive (which mostly holds zeros) weighs more than a full USB drive (which has ones and zeros). But you'd need to weigh more USB drives than exist before the weight difference became measurable. ***PB***

CAN SMART SPEAKERS EAVESDROP ON OUR CONVERSATIONS?

Smart speakers sit quietly in your room, listening to you all the time. They are waiting for key phrases such as 'Hey Siri', 'Alexa', or 'OK Google' Once they've heard them, they start recording your voice and upload it to the cloud so they can figure out what you said. But the only way a smart speaker can be used to continuously record conversations is for it to be hacked, to change its core software. Smart speakers are not unique in this sense – most of us walk around with internet-connected microphones as part of our smartphones, which can also be hacked. *PB*

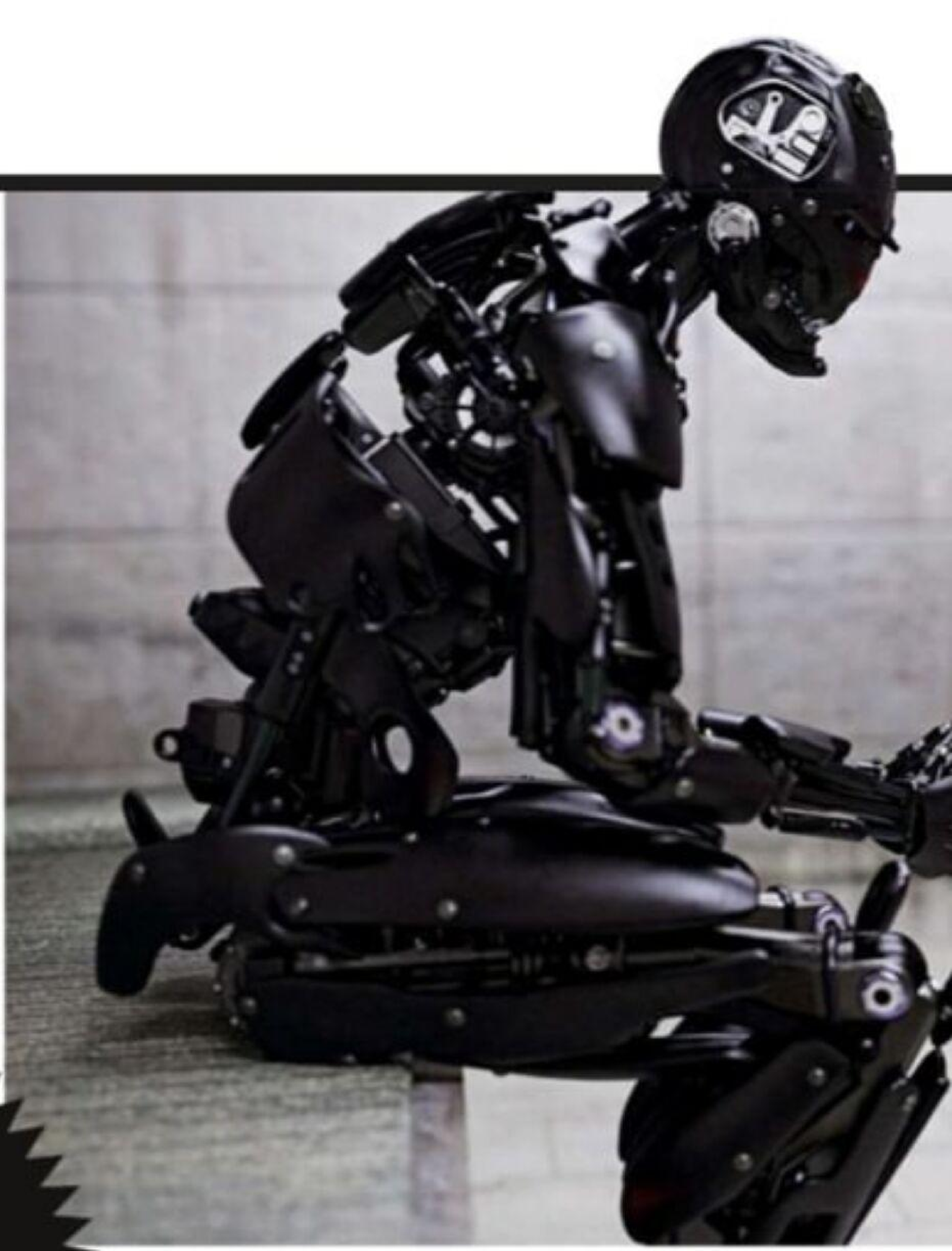
DOES A COMPUTER KNOW THAT IT'S A COMPUTER?

Despite all the amazing advances in artificial intelligence, there's no computer today that understands that it's a computer, and knows what that means. Computers generally know very little about the world – they focus on specific sets of data to solve specific problems. What self-awareness or consciousness would mean for a computer is long-debated, and it's notoriously difficult to create and test. One of the best examples so far was an experiment in the US in which three robots were given a virtual 'pill' that muted just two of them. They were then asked which pill they received. Two remained silent, while one stood up and said "I don't know," quickly followed by, "Sorry, I know now. I was able to prove that I was not given the dumbing pill." ***PB***

REJECT
CHAPPIE

In 2015's *Chappie*, the titular robot is given new programming to think for itself

STRATOLAUNCH, ALAMY, SHUTTERSTOCK



WHO REALLY INVENTED...?

GPS

ROGER EASTON

BRADFORD PARKINSON

IVAN GETTING

Originally developed in the 1970s for use by US armed forces, the Global Positioning System (GPS) network of 30-plus satellites has since found uses in everything from archaeological surveys to self-driving cars.

In 2003, physicist Dr Ivan Getting and engineer Col Bradford Parkinson were awarded the Draper Prize for making GPS a reality. But while no one disputes their role, neither were responsible for the key to the system's success: fitting each satellite with an 'atomic clock'.

In the late 1950s, Getting and his team were working on Transit, a satellite network whose radio signals could be used to fix locations on Earth. The technique needed accurate timekeeping, but the quartz clocks being used weren't reliable enough. In 1964 the US Navy began work on the Timation programme – a network of orbiting atomic clocks that would keep time using more stable quantum effects.

The Timation programme was masterminded by Dr Roger Easton, and Parkinson led the drive to get the technology out of the lab and into orbit. It took until 2010 for Easton join the others in the US National Inventors Hall of Fame. *RM*

Where am I? A network of orbiting atomic clocks lets GPS answer that question for you

$90m

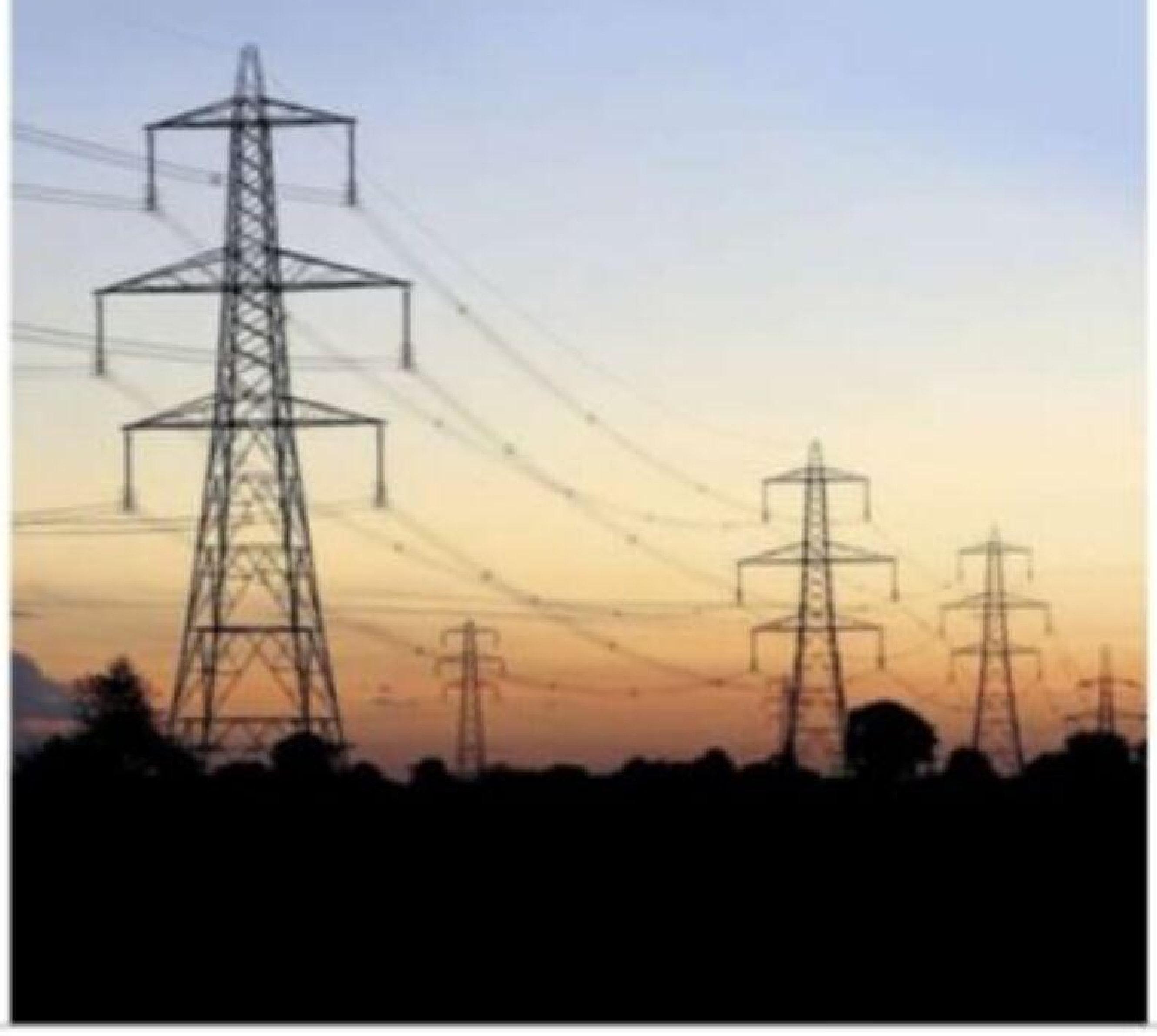
Currently the cheapest cost, in US dollars, of launching the Falcon Heavy rocket, the commercial launch vehicle operated by Elon Musk's SpaceX company. Prices go up to $150m

WHY DO PASSENGER AIRCRAFT FLY SO HIGH?

There are lots of benefits to flying at an altitude of 11km. The air is thinner, producing less aerodynamic drag and thus reducing fuel consumption. It is also cold, around -55°C, which boosts the efficiency of the jet engines. Plus, this part of the atmosphere – known as the stratosphere – is less turbulent, making for a smoother flight. *RM*

WHY DO HIGH-VOLTAGE POWER LINES CRACKLE AND HISS?

It's primarily the effect of the high voltage on the air surrounding the cable. Air is normally a very poor conductor of electricity. But if a sufficiently high voltage is applied across a small distance, electrons from the air molecules are stripped off and start to form a current. This in turn causes intense heating of the air – resulting in crackle and hiss. It's most common during damp weather, when the air becomes a better electrical conductor. *RM*



USAF, GETTY IMAGES X4, RAJA LOCKEY

IF AN AI BECAME SENTIENT, WOULD IT GAIN HUMAN (OR EQUIVALENT) RIGHTS?

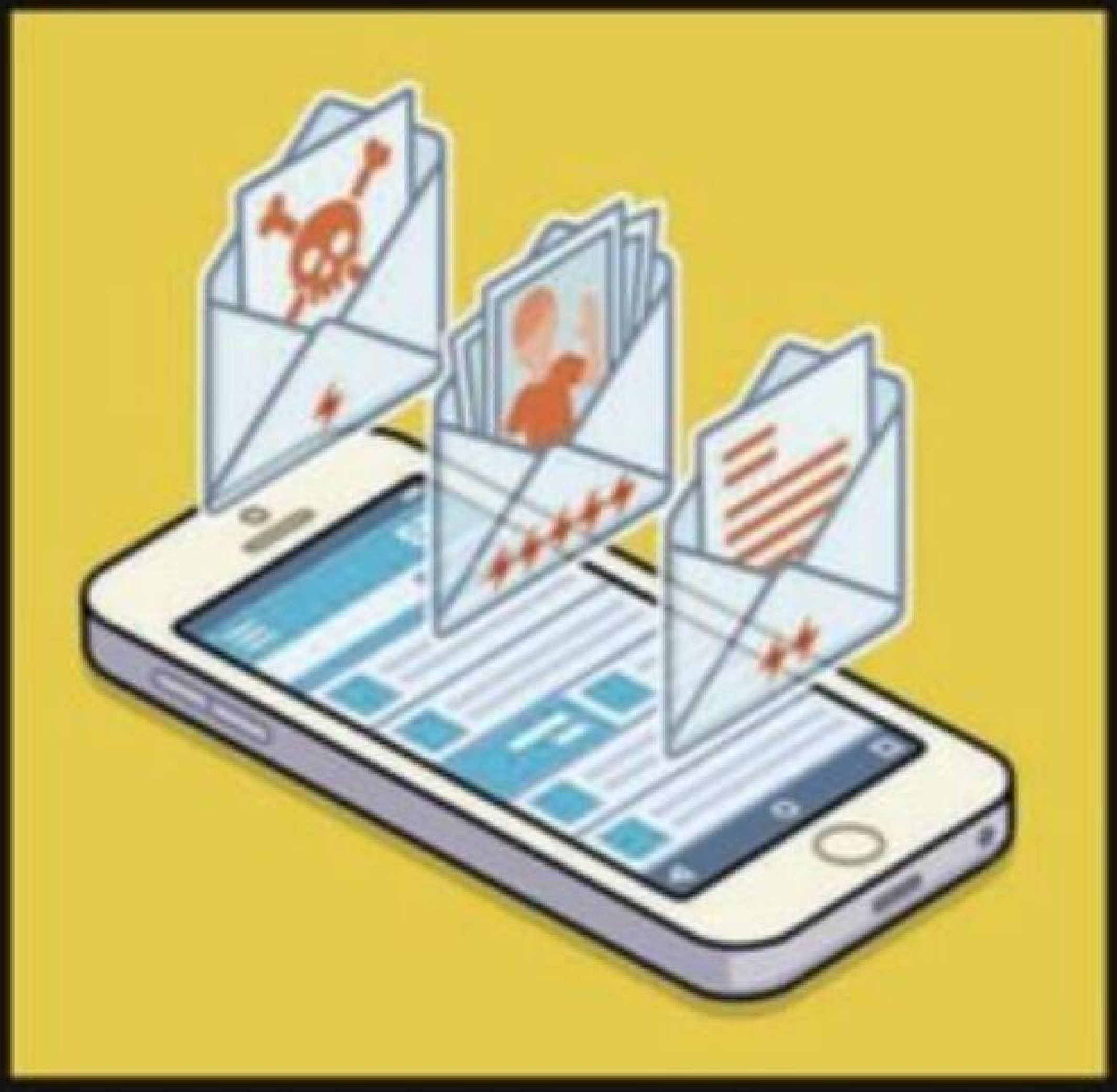
We call a creature sentient if it can perceive, reason and think, and also if it might suffer or feel pain. Scientists suggest that all mammals, birds and cephalopods, and possibly fish too, may be considered sentient. However, we do not grant rights to most creatures, so a sentient AI may not gain any rights at all. AIs also have another big problem: they lie to us. Today's AIs all pretend to understand us and have emotions. If you ask Siri if it is happy, it may say it is overjoyed, but the words are hollow – it feels nothing. This makes it even harder for the AIs of the future. How do we know if the AI is sentient, or if it's just pretending? ***PB***

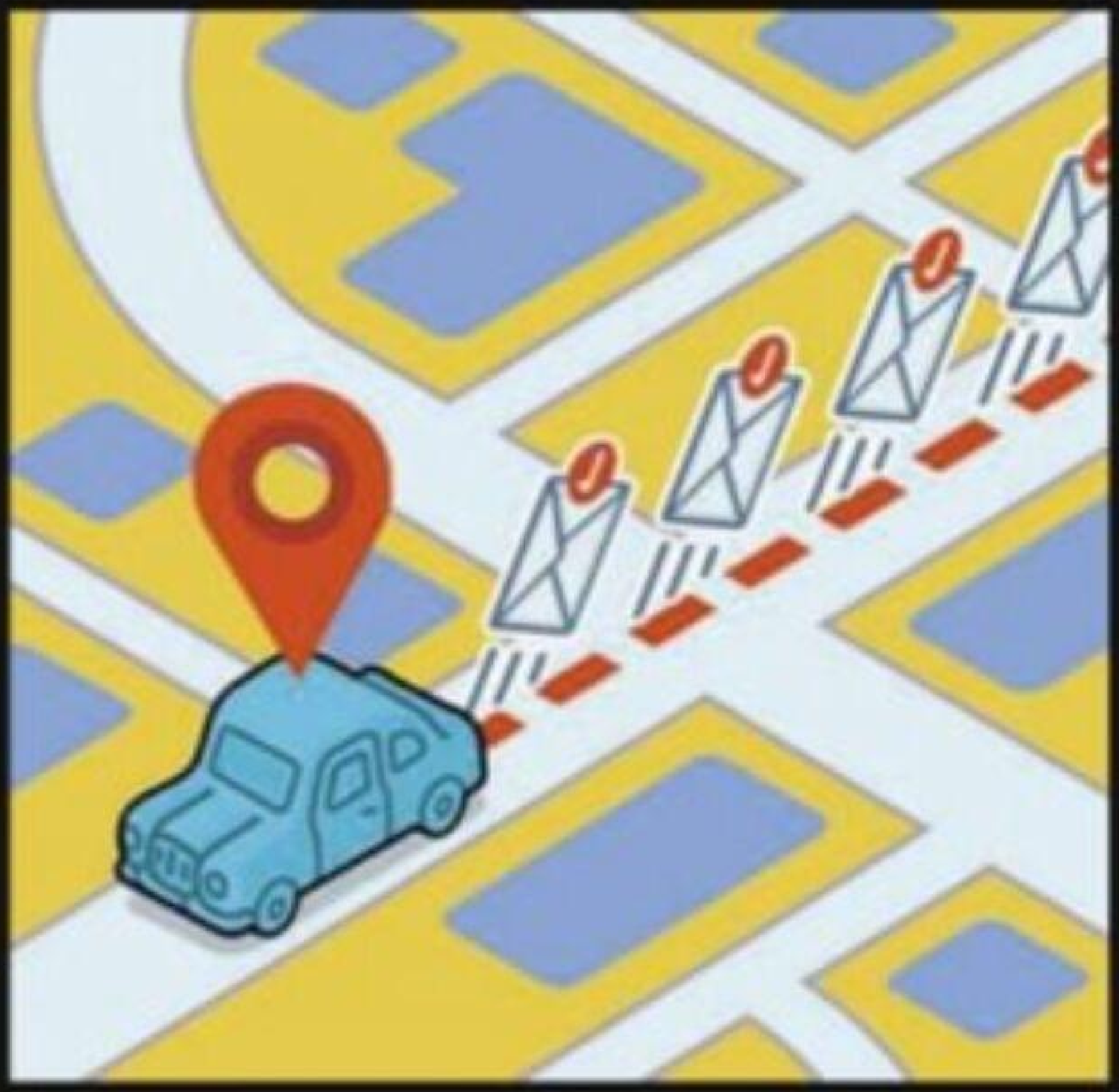
WHY IS TELEVISION SO ADDICTIVE?

The idea that technologies, such as TV, can be considered truly addictive in the same way as substances like nicotine and alcohol is controversial. Nonetheless, many of us spend huge amounts of time watching TV (often more than we would like). Alongside the pulling power of cliffhangers and plot twists, TV's main attraction comes from its ability to serve many of our most basic psychological needs. It allows us to alter our emotions, to learn, to find out what's happening in the world and to enjoy 'para-social' relationships with fictional characters. And all this from the comfort of our sofas. ***CJ***

THE THOUGHT EXPERIMENT

WHAT'S THE CARBON FOOTPRINT OF AN EMAIL?





1. LESS ENERGY THAN LETTERS

Every email we send uses electricity to display it, and the network connection uses electricity while the email is being transferred. As the email travels across the internet, each server will use some electricity to temporarily store it, before passing it on. Still, sending an email only uses about 1.7 per cent of the energy of delivering a paper letter – but we do send more emails!

2. ADD ATTACHMENTS

For a typical email, this electricity is responsible for 4g of CO_2 emissions. If it has a picture attachment, this needs extra storage and takes longer to transmit, so the carbon footprint rises to an average of 50g. Spam emails are mostly deleted automatically by the email servers before you see them so they don't travel as far and only produce 0.3g each.

3. COMPARE TO YOUR CAR

Sending 65 emails is roughly equivalent to driving 1km in a car. In a year, an average person in the developed world adds 136kg of CO_2 to their carbon footprint from the emails they send and receive. This is equivalent to an extra 320km driven in a car. Globally, the world's email usage generates as much CO_2 as having an extra seven million cars on the roads.

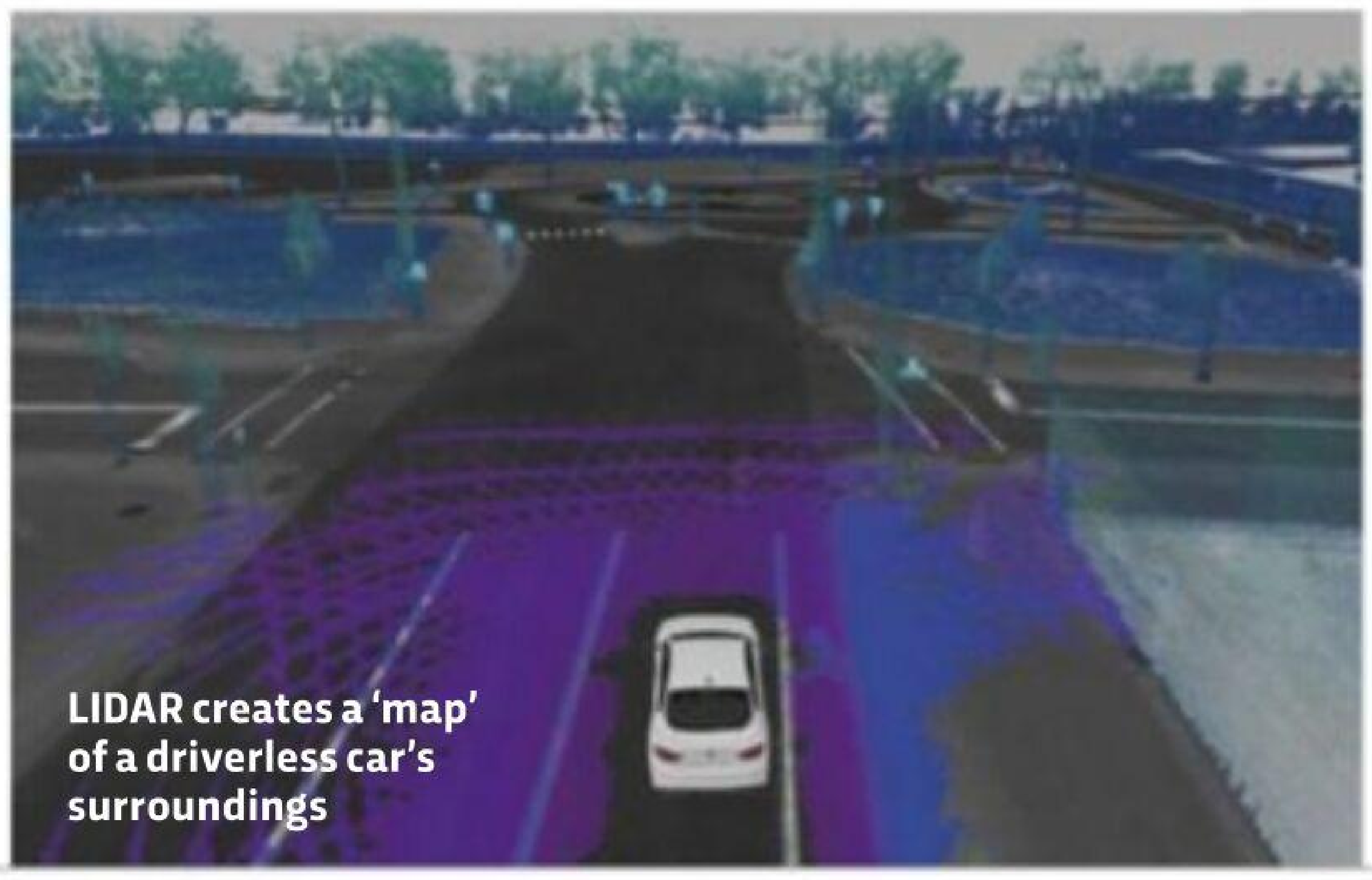
LEGOLAND HOTEL

WHY AREN'T LARGE LEGO BRICKS USED TO BUILD FULL-SIZE BUILDINGS?

An ordinary Lego brick can support 375,000 others before it fails, which would allow you to build a tower almost 3.5km high! But Lego is too expensive to be used as a large-scale building material. There are, however, Lego-style construction techniques that use other materials. Insulated concrete formwork uses hollow polystyrene blocks to build walls that are then filled with concrete. And in developing countries, interlocking blocks of compressed earth mixed with cement are used as an alternative to bricks and mortar. ***LV***

WOULD IT BE POSSIBLE FOR AUTONOMOUS CARS TO USE ECHOLOCATION ?

Sending out sound waves and listening for their echo is a great way to detect obstacles in water – submarines can detect objects many kilometres away. But sound doesn't travel nearly so well in air. Bats can only detect objects up to 20 metres away, falling to around two metres in poor conditions. Light is less affected by atmospheric conditions, which is why self-driving cars use LIDAR ('light detection and ranging'), bouncing infrared laser light off objects in order to detect them. ***PB***


LIDAR creates a 'map' of a driverless car's surroundings

IS THERE A WAY THAT THE INTERNET COULD BE SWITCHED OFF WORLDWIDE?

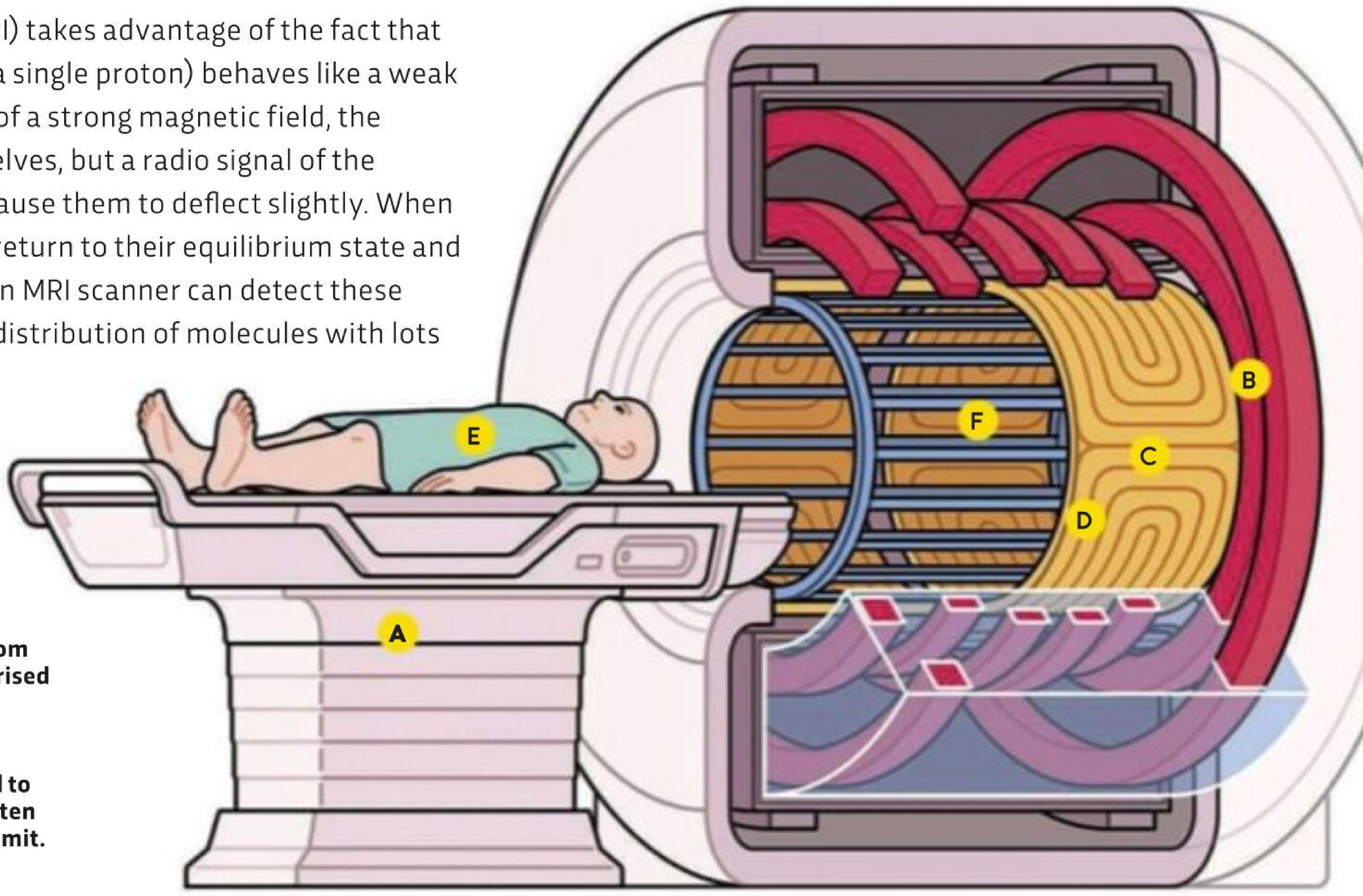
No. This is like asking "could you stop every river in the world at once?". You can dam or divert individual streams, but it is virtually impossible to block them all simultaneously, because the water always tries to find a new route downhill.

Likewise, the internet is a huge and complex structure operated by a mixture of government and commercial bodies – as well as billions of private individuals. There isn't a single connection point through which all the data flows, and the internet protocol was specifically designed so that data finds a route around parts of the network that are down.

But the internet isn't entirely invulnerable, either. In 2011, during the Egyptian Revolution, the Egyptian government ordered the four national internet service providers to turn off the Domain Name System (DNS) and alter the Border Gateway Protocol of their servers. This prevented any internet traffic in or out of the country. The UK has the legal authority to do the same thing in the event of a national crisis, but this power has never been used. And if the US for some reason ordered Microsoft, Apple, Facebook and Google to turn off their servers, the internet would be as good as shut down for most of us. *LV*

THE MRI SCANNER

Magnetic Resonance Imaging (MRI) takes advantage of the fact that the nucleus of a hydrogen atom (a single proton) behaves like a weak compass needle. In the presence of a strong magnetic field, the hydrogen atoms will align themselves, but a radio signal of the correct resonant frequency will cause them to deflect slightly. When the signal is removed, the atoms return to their equilibrium state and emit a radio signal of their own. An MRI scanner can detect these signals and use them to map the distribution of molecules with lots of hydrogen atoms – ie, water and fat. In this way, it can create detailed images of the inside of the body.



A SCANNING TABLE
The patient can only be scanned from inside the magnetic coil, so a motorised table slides them in and out.

B RF SYSTEM
An antenna produces a radio signal to 'nudge' the hydrogen nuclei and listen to the answering radio wave they emit.

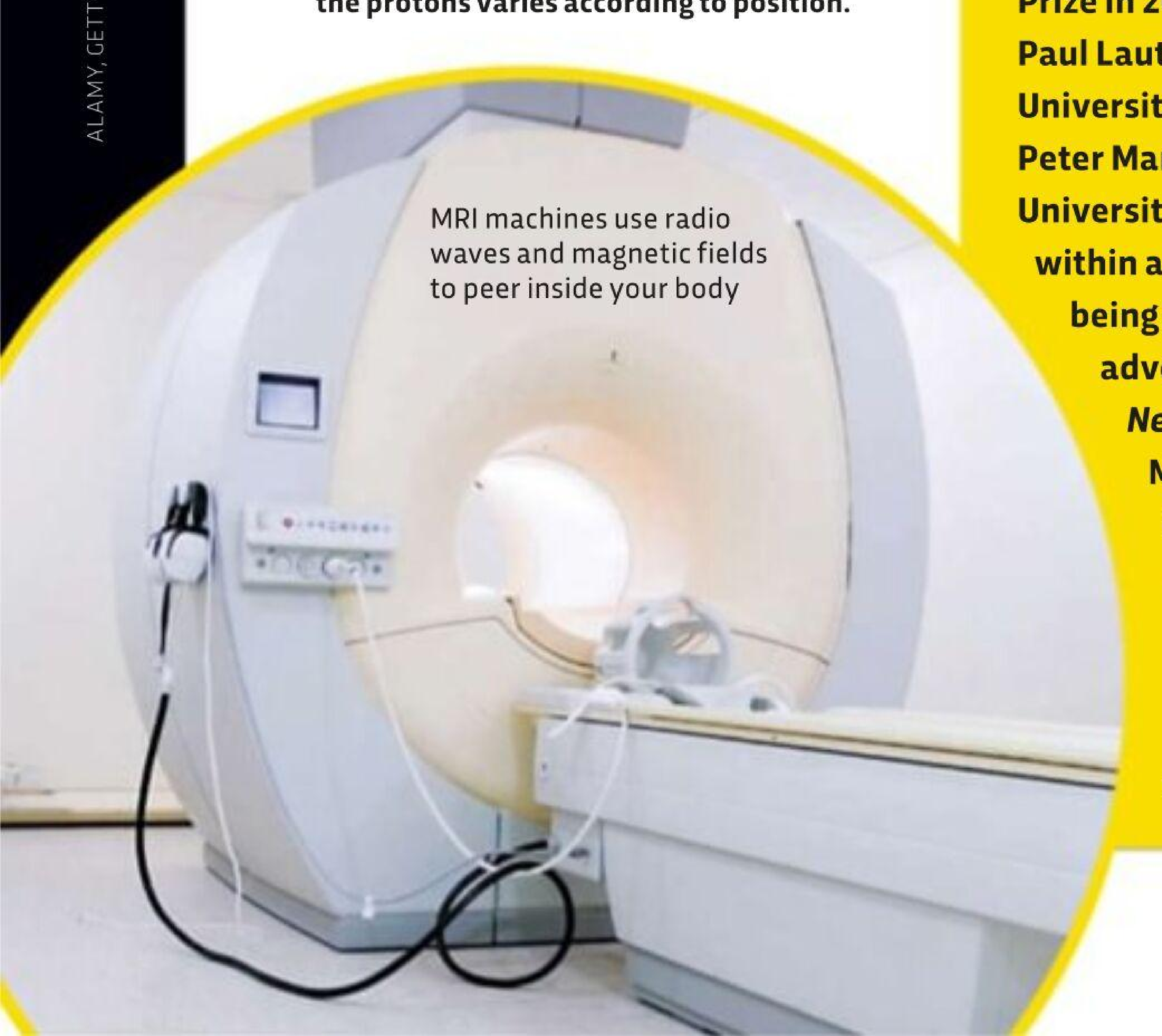
C LIQUID HELIUM
Liquid helium is pumped through an enclosing jacket to cool the superconducting magnets almost to absolute zero.

D MAIN MAGNET
Superconducting magnetic coils produce a magnetic field of 1.5 teslas – that's about 300 times stronger than a fridge magnet.

E PATIENT
The high magnetic fields mean that patients with cochlear implants, pacemakers or embedded shrapnel usually can't be scanned.

F GRADIENT SYSTEM
A second coil distorts the main magnetic field so that the resonant frequency of the protons varies according to position.

ALAMY, GETTY IMAGES X4, RAJA LOCKEY



MRI machines use radio waves and magnetic fields to peer inside your body

WHO REALLY INVENTED...? THE MRI SCANNER

With its ability to image the internal organs and functioning of the body without using X-rays, magnetic resonance imaging (MRI) ranks as one of the biggest medical breakthroughs, and its development led to a Nobel Prize in 2003 for two scientists: Paul Lauterbur of the State University of New York and Peter Mansfield of the University of Nottingham. But within a month of the prize being announced, a full-page advert appeared in *The New York Times* insisting MRI was actually invented by a New York doctor named Raymond Damadian. MRI exploits so-called nuclear magnetic resonance (NMR) in which hydrogen nuclei in our bodies are first gripped by powerful magnetic fields, then stimulated into producing radio waves. As these signals are affected by the nature of the tissue, Damadian was among those who thought NMR might help with the early detection of cancer. By the early 1970s the idea had shown promise, and Damadian was granted a patent for this use of NMR. But others were already going further and trying to create clear images from the signals. Lauterbur and Mansfield are widely regarded to have carried out the most work towards solving the technical issues involved, turning MRI into the versatile technique it is today. *RM*

PETER MANSFIELD

PAUL LAUTERBUR

RAYMOND DAMADIAN

CROWDSCIENCE

HOW GREEN ARE ELECTRIC CARS?

We teamed up with the folks behind BBC World Service's *CrowdScience* to answer your questions on electric cars. Tune in to *CrowdScience* every Friday evening on BBC World Service, or catch up online at bbcworldservice.com/crowdscience

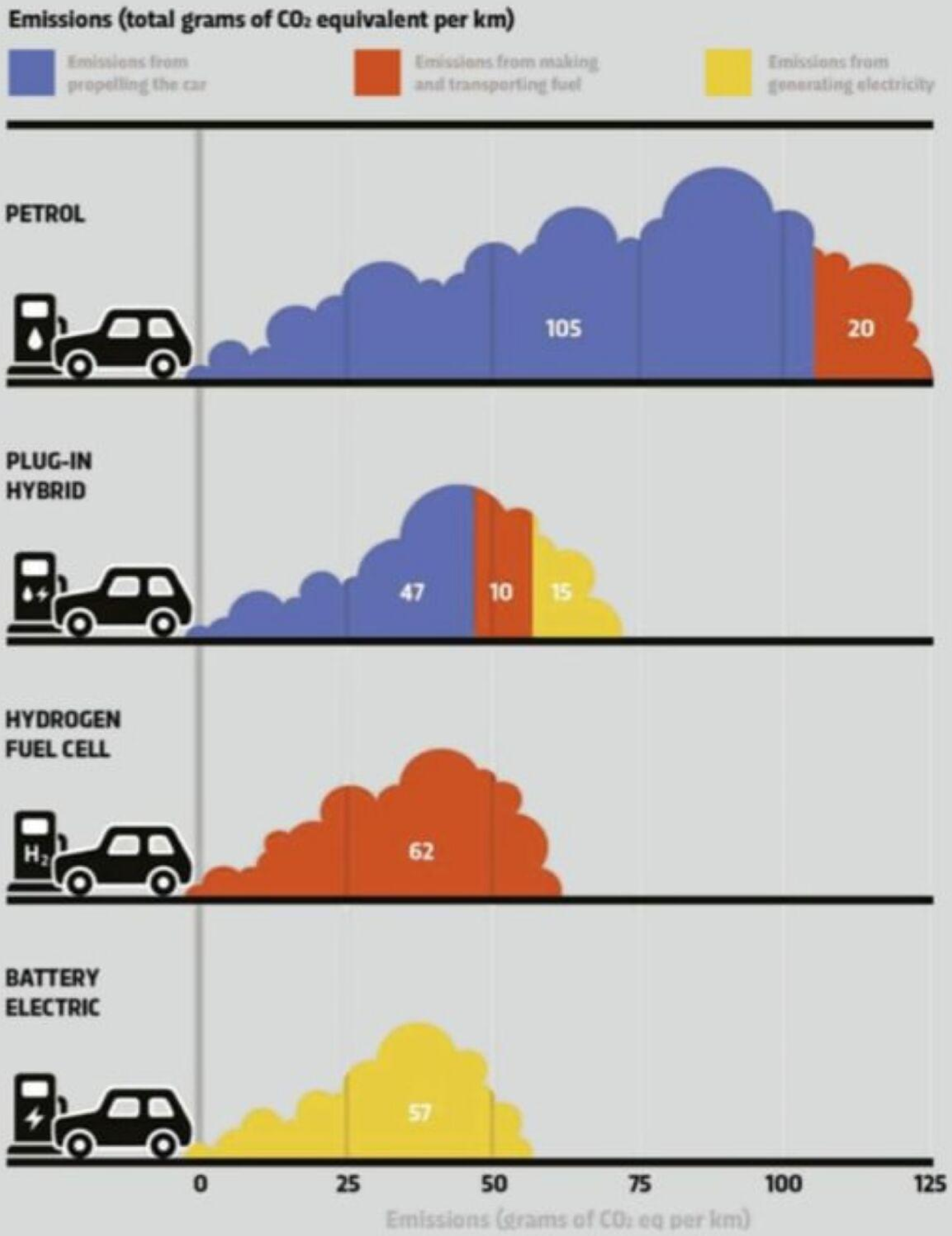
ARE HYDROGEN CARS GREENER THAN ELECTRIC CARS?

An electric car with a hydrogen fuel cell instead of a lithium-ion battery offers emissions-free driving (the hydrogen combines with oxygen from the air, and the exhaust is water) and fast refuelling. It takes five minutes to fill tanks of compressed gas, but at least 40 to charge a battery. Currently, most hydrogen is made from natural gas, which is an energy-intensive process that needs high temperatures. Soon hydrogen could be made by electrolysis (splitting water) using solar-supplied electricity, making it as green as any renewables-powered electric car. ***JS***

HOW DO ELECTRIC CARS COMPARE WITH PETROL CARS?

It depends on how power is generated where you live. If you have solar panels, then your driving will be emission free. If your electricity comes from a plant powered by fossil fuels, then you're just shifting your emissions from your exhaust to its chimneys. But even in areas with coal-fired plants, electric cars still have lower CO_2 emissions overall, because large power stations turn fuel into energy more efficiently than small engines, and it's easier to clean up the chimney stacks' emissions. Also, electric cars will get cleaner if a wind farm or other renewable energy source opens nearby. ***JS***

Jack Stewart presented an episode of *CrowdScience* looking at electric cars. He also writes about transport for *Wired*.



Emissions (total grams of CO_2 equivalent per km)

Park up, plug in and recharge – on-street charging will become an increasingly familiar sight

ARE ELECTRIC CARS FINALLY ABOUT TO CATCH ON?

Manufacturers are now convinced that they can build electric cars with a comparable range and speed to their petrol counterparts. The key is developing cheaper and lighter lithium-ion batteries that can store ever more energy. The technology still isn't mainstream: in the UK, just 1.5 per cent of cars come with plugs. However, in Norway, where there are huge tax breaks and perks like being able to use bus lanes, it's up to 29 per cent. This shows that, with government incentives, people are willing to start driving electrics, and sales are predicted to spike when the price falls to the level of a petrol equivalent – forecast to happen in the early 2020s. ***JS***

Lithium-ion batteries, are commonly used in electric cars because of their high energy to weight ratio

GETTY IMAGES X3

FOR ELECTRIC CARS CHARGED FROM THE MAINS, WHAT IS THE CO_2 PER MILE?

There are many variables to consider. Roughly speaking, in the UK, an electric car charged from the mains currently emits roughly 80g of CO_2 per mile, compared to 216g CO_2 per mile for the average petrol car. An electric car's emissions depend on what proportion of its electricity is derived from burning fossil fuels, and therefore varies from country to country, and according to the time of day. As we generate more energy from renewable sources, the carbon emissions of electric cars will drop further. ***AFC***

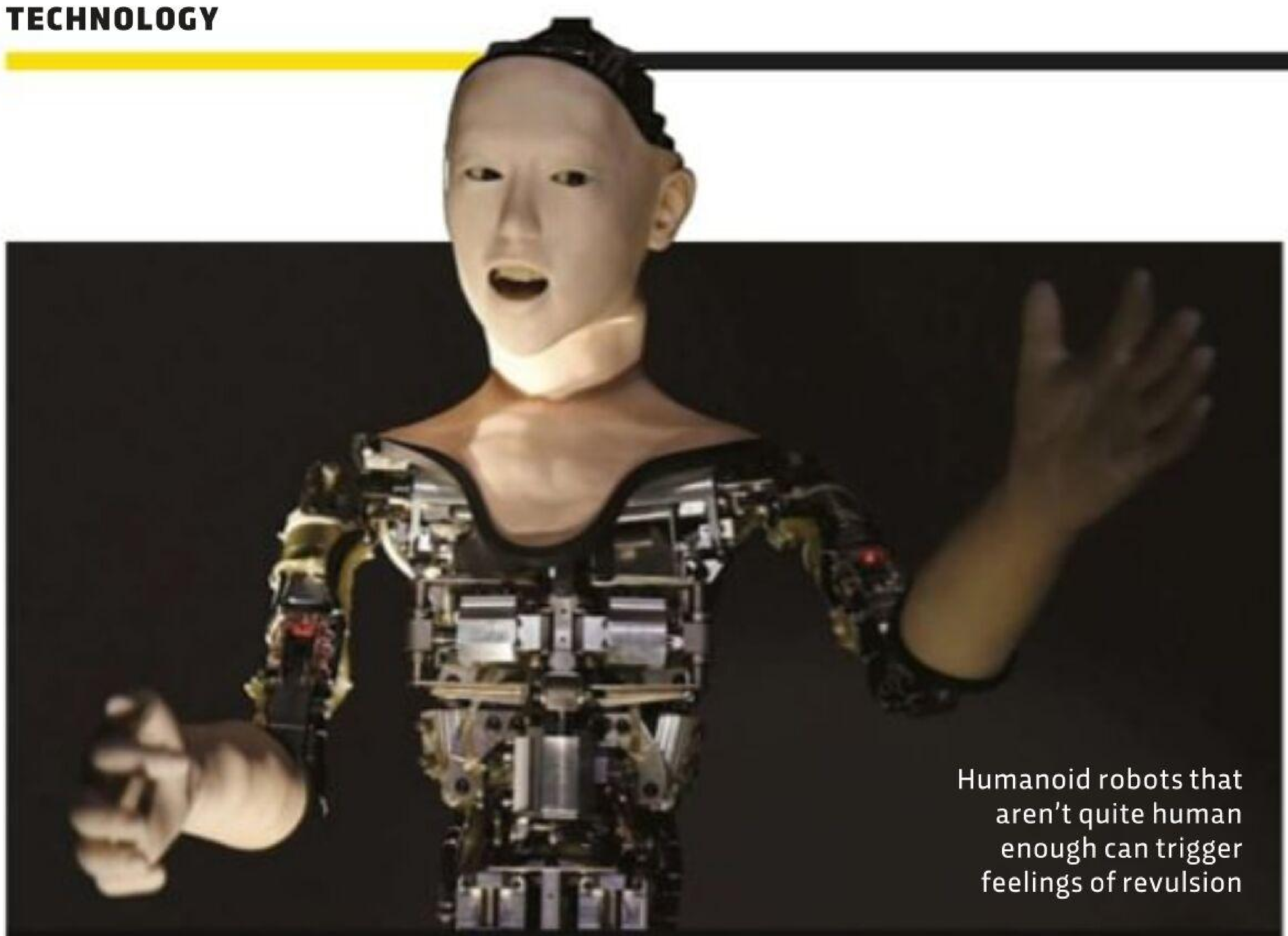
Figures are from the 2014 EU study *Well-to-wheels analysis of future automotive fuels and powertrains in the European context*, and assume an 'EU-mix' of electricity generation – an average of European energy sources.

COULD DYNAMOS BE INSTALLED IN THE WHEELS OF AN ELECTRIC CAR TO PROVIDE A PERPETUAL SOURCE OF POWER?

We already recover power from the wheels of some cars when slowing. Kinetic energy recovery systems (KERS) have been used in Formula One racing to store energy in a flywheel when braking, and then push it back to the wheels later for a boost in speed. Electric cars often use regenerative braking, which converts the speed of the wheels into electrical power to recharge the battery. These systems are a great way to increase efficiency, but like everything in the Universe, they are not 100 per cent efficient. Sadly, the laws of physics prohibit the existence of true perpetual motion, so it's the best we can do. ***PB***

DOES A CRASHED ELECTRIC VEHICLE POSE A FIRE OR ELECTROCUTION RISK?

Despite their green image, lithium batteries can turn pretty nasty if damaged. In electric vehicles, they are surrounded by coolant. If that leaks out, the batteries can heat up and catch fire. They also contain electric charge, and emergency service personnel have to avoid touching or cutting into the high-voltage units as the consequences can be deadly. Vehicle designers have worked hard to reduce the fire and electrocution risks, but so far they've been unable to completely eliminate them. ***RM***



Humanoid robots that aren't quite human enough can trigger feelings of revulsion

WHY DO WE MAKE ROBOTS LOOK LIKE HUMANS?

We've always been fascinated by the idea of creating autonomous machines that resemble us, and if they need to interact closely with us, we prefer them to look familiar. Human-like robots, such as Honda's ASIMO, Boston Dynamics' Atlas and the childlike iCub built by the Italian Institute of Technology, are amazing demonstrations of our technology, but they still have a long way to go – and when they look nearly human but not quite, they end up looking seriously freaky to us. Perhaps we should just let robots be the shape they need to be, in order to best carry out their function. ***PB***

0.38

The time, in seconds, it took a robot built by Ben Katz and Jared Di Carlo of MIT to solve a Rubik's cube, breaking the previous world record of 0.637 seconds. The fastest human time for solving the puzzle is currently 4.22 seconds

HOW ARE FRAGRANCES REMOVED TO MAKE FRAGRANCE-FREE PRODUCTS?

sensitive - fragrance free
NATURAL DEODORANT STICK

'Fragrance-free' doesn't mean that a cosmetic product doesn't smell of anything. It means that it doesn't have any fragrance chemicals in it. These might be synthetic fragrances, but they could also be certain natural compounds, such as fruit oils. However, labelling regulations only affect compounds that could cause skin irritation. Other ingredients such as olive oil or shea butter have a mild scent but they don't count as fragrances for the purposes of product description. Cosmetics referred to as unscented have been formulated to remove any smell, but they do this by adding masking chemicals, such as phthalates, rather than actually removing the scent molecules. ***LV***

IS PLASTIC CURRENCY MORE OR LESS HYGIENIC THAN ITS PAPER EQUIVALENT?

A 2013 study (published before the UK switched to plastic banknotes) found that the polymer currency used in Romania allowed MRSA superbugs to survive for 24 hours, compared with just three hours for paper notes. But subsequent studies on the new polymer £5 note have found that harmful germs are much less likely to stick to the plastic in the first place. ***LV***

Solar panels produce electricity without releasing CO_2 or other harmful pollutants

GETTY IMAGES X5, ALAMY X2

DO SOLAR PANELS WORK BETTER ON HOT DAYS?

Surprisingly, they perform worse as the temperature rises! Solar panels work by using incoming photons to excite electrons in a semiconductor to a higher energy level. But the hotter the panel is, the greater the number of electrons that are already in the excited state. This reduces the voltage that the panel can generate and lowers its efficiency. Higher temperatures also increase the electrical resistance of the circuits that convert the photovoltaic charge into AC electricity. Modern hybrid solar panels are designed to suffer less from the heat, but they can still lose 10 per cent of their rated efficiency on hot days. ***LV***

WHO REALLY INVENTED…?

THE FLUSHING TOILET

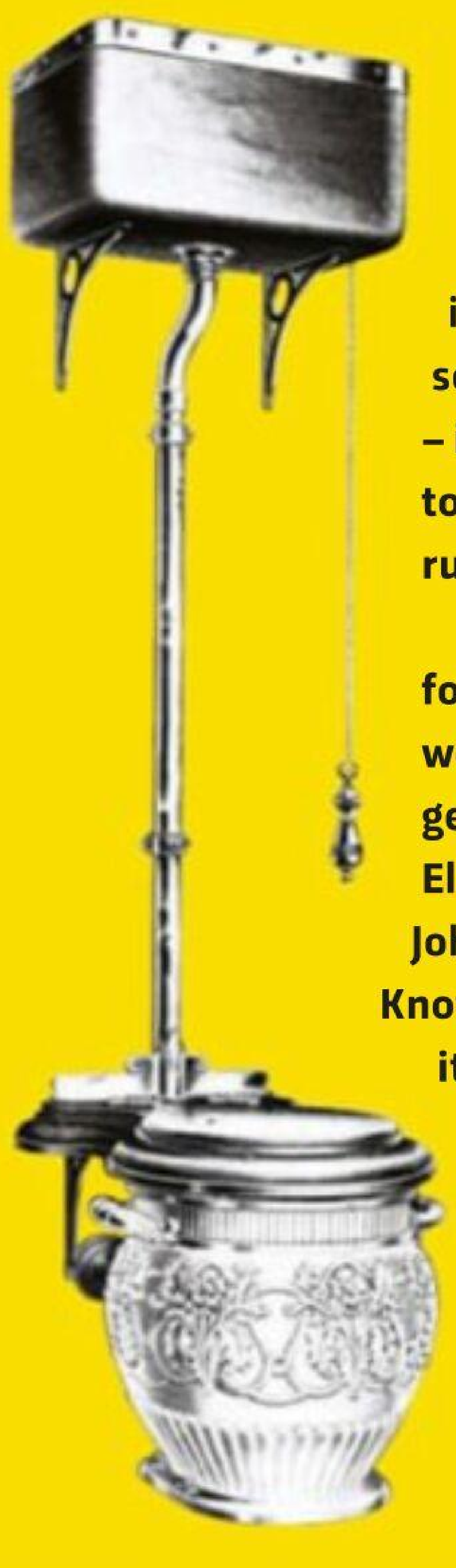
SIR JOHN HARINGTON

THOMAS CRAPPER

This question always raises a smile among those who know the answer – or at least, think they do. That's because the invention of what is often rated as one of the most important contributions to human health is often attributed to a Victorian plumber named Thomas Crapper.

Crapper certainly existed, and he was an innovator, patenting the U-bend and floating ballcock – key parts of the modern toilet. Commercially, he also did much to encourage the installation of handbasins alongside toilets. As such, Crapper does have a claim to have invented the lavatory, which is the term for a room combining the two.

But Crapper did not invent the flushing toilet.



The basic idea of using water to wash away sewage dates back to the Bronze Age. Around 4,000 years ago, cities in the Indus Valley had sophisticated sanitation – including communal toilets flushed with running water.

Credit for inventing the forerunner of the device we're familiar with today generally goes to the Elizabethan courtier Sir John Harington in 1596. Known as a water closet, it was installed in Richmond Palace. Yet despite this royal support, the device was long rejected by the public, who saw it as an expensive indulgence. *RM*

FALSE BAY, SOUTH AFRICA

What is this?

These two otherworldly creatures are predator and prey. On the left: the blue sea slug (which appears almost black). On the right: the deadly tentacle of the Indo-Pacific Portuguese man o' war. Both were washed ashore as part of a mass stranding in South Africa. The Indo-Pacific Portuguese man o' war is a ruthless killer, using its single, long tentacle to stun and capture its prey. But the sea slug is more than a match. Not only does this 3cm-long nudibranch feed on man o' wars, it also steals their poison. The sea slug is immune to the man o' wars stinging cells, so it consumes them and stores them in the tips of its tendrils to fight off other foes.

TONY WU/NATUREPL.COM

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WHY DO GIRAFFES HAVE PURPLE TONGUES?

Their preferred food of lush green leaves may not be cooked, but giraffes still run the risk of burning their tongues

If you've ever been lucky enough to be licked by a giraffe, you'll notice that their 50cm-long tongues can appear purple, bluish or almost black in colour. This is due to the density of dark 'melanin' colour pigments in them. There's still no definitive explanation for this, but the leading theory is that the melanin provides extra UV protection, preventing their delicate tongues from getting sunburned as they feed up high. ***CC***

ANIMALS

CATS, DOGS, WHALES, OYSTERS, OCTOPUSES, DINOSAURS, SEAGULLS, SLUGS, BUGS AND CHICKENS…

DO ANY OTHER ANIMALS PLAY MUSIC?

Plenty of non-human animals create sounds that we might consider music and there's even a whole field of study dedicated to this idea: zoomusicology. Birdsong is undoubtedly the most familiar of these sounds, but is it truly music? A 2012 study of nightingale-wrens found that their songs don't match up with Western musical scales, so the musicality of birds might be something of an illusion – to our ears, at least. For the most human-like music, we might need to go underwater. The male humpback whale produces complex songs with structures that are remarkably similar to our own, consisting of looping sequences of 'melodies' and repeating 'end phrases' akin to the rhymes in song lyrics. Little wonder then that 1970 album *Songs Of The Humpback Whale* went multi-platinum. ***CC***

WHY DON'T HORSES HAVE TOES?

Early horses such as Hyracotherium, which lived 55 million years ago, did have multiple toes, but they were much smaller animals. For taller animals, excess weight at the end of their legs has a much bigger impact on their speed. A recent study at Harvard found that one broad hoof is almost as strong as multiple smaller toes, but much lighter. Natural selection has gradually discarded the horse's side toes and widened the middle one to increase running speed. ***LV***

WHY DO DOGS TILT THEIR HEADS WHEN YOU SPEAK TO THEM?

A dog's range of hearing is wider than ours but not as accurate. Perking their ears up while tilting their heads helps them pinpoint where noises are coming from more quickly. It also helps them to hear and interpret the tone of our voices, and pick out familiar words such as 'walkies'. Dog behaviour expert Dr Stanley Coren believes that dogs with shorter muzzles tilt their heads less because they have a better view of our facial expressions and are therefore not so reliant on their ears to understand us. ***CC***

GETTY IMAGES X3

BY WEIGHT, WHICH ANIMAL HAS THE LARGEST BABY RELATIVE TO BODY SIZE?

Despite a kiwi being about the size of a chicken, the female lays an egg that is about half her weight! It's so big because it has an enormous yolk, which sustains the chick for the first week of its life. Here are some other animals that have enormous babies, as well as those that have teeny tiny offspring (with humans thrown in for good measure). ***LV***

KIWI (EGG)
(1/2)

GIRAFFE
(1/10)

BELUGA WHALE
(1/17)

HUMAN
(1/22)

ELEPHANT
(1/26)

GIANT CLAM
(1/500,000,000)

OCEAN SUNFISH
(1/1,500,000)

RED KANGAROO
(1/100,000)

HONEY POSSUM
(1/2,400)

GIANT PANDA
(1/900)

Fish may be a seagull's first choice in its natural habitat but chips will suffice if it's living in a city

WOULD SEAGULLS EXIST WITHOUT HUMANS?

The gulls mostly seen in UK towns are herring gulls. Since the 1960s they've increasingly been migrating inland to live and feed: this is largely due to overfishing and the rising sea temperatures due to climate change, which is forcing fish to greater depths to find plankton. The gulls scavenge in landfill sites and areas where we feed them. Although often seen as a nuisance, some species of seagulls are endangered. Without humans, their natural food supply would recover so, on balance, they'd be much better off without us. ***CC***

DO ANIMALS GO THROUGH PUBERTY?

Puberty is the process we go through to become reproductively functional. It's characterised by the physical, chemical and sometimes social changes that occur during sexual maturity. Some animals, like the Cabrera's hutia (a rodent that lives in Cuba), reach this point when they get to an exact weight of 360g for females, or 300g for males. But for most other animals, the timing of puberty is age-related. Insects and amphibians experience 'metamorphosis', going through two or more stages of development to move from hatching or birth to adulthood. Meanwhile, some aphid and mite species speed things up by being born pregnant, with the next generation of eggs already growing inside them. So puberty, in one form or another, is a shared and necessary evil across the whole of the animal kingdom. ***CC***

A monarch spends about 10 to 14 days as a chrysalis before emerging as a butterfly

IS AUTISM FOUND IN ANY OTHER ANIMALS?

Autism is a neurodevelopment condition found in humans, and some of the diagnostic criteria, such as a delay in language development, can't apply in a straightforward way to animals. That said, some animals do display autistic-like traits, such as a tendency toward repetitive behaviour or atypical social habits. Bull terriers, for example, are especially prone to repetitive tail chasing, which some experts liken to the spinning that is sometimes seen in children with autism. ***CJ***

GETTY IMAGES X12, FLPA X2

WHY DO LIONS HAVE MANES?

At the onset of sexual maturity, male lions start to grow thick manes around their head, neck and belly. The hormone testosterone is responsible for this – interestingly, neutered males usually lose their manes entirely. Females are attracted to bigger, darker manes, so it seems that manes are a signal of sexual fitness. Lions often live in open savannah habitats, so it's beneficial to have evolved a visual means of signalling strength and status. Manes also provide protection from injury when males fight. ***CC***

WHY DO WOMBATS DO CUBE-SHAPED POOS?

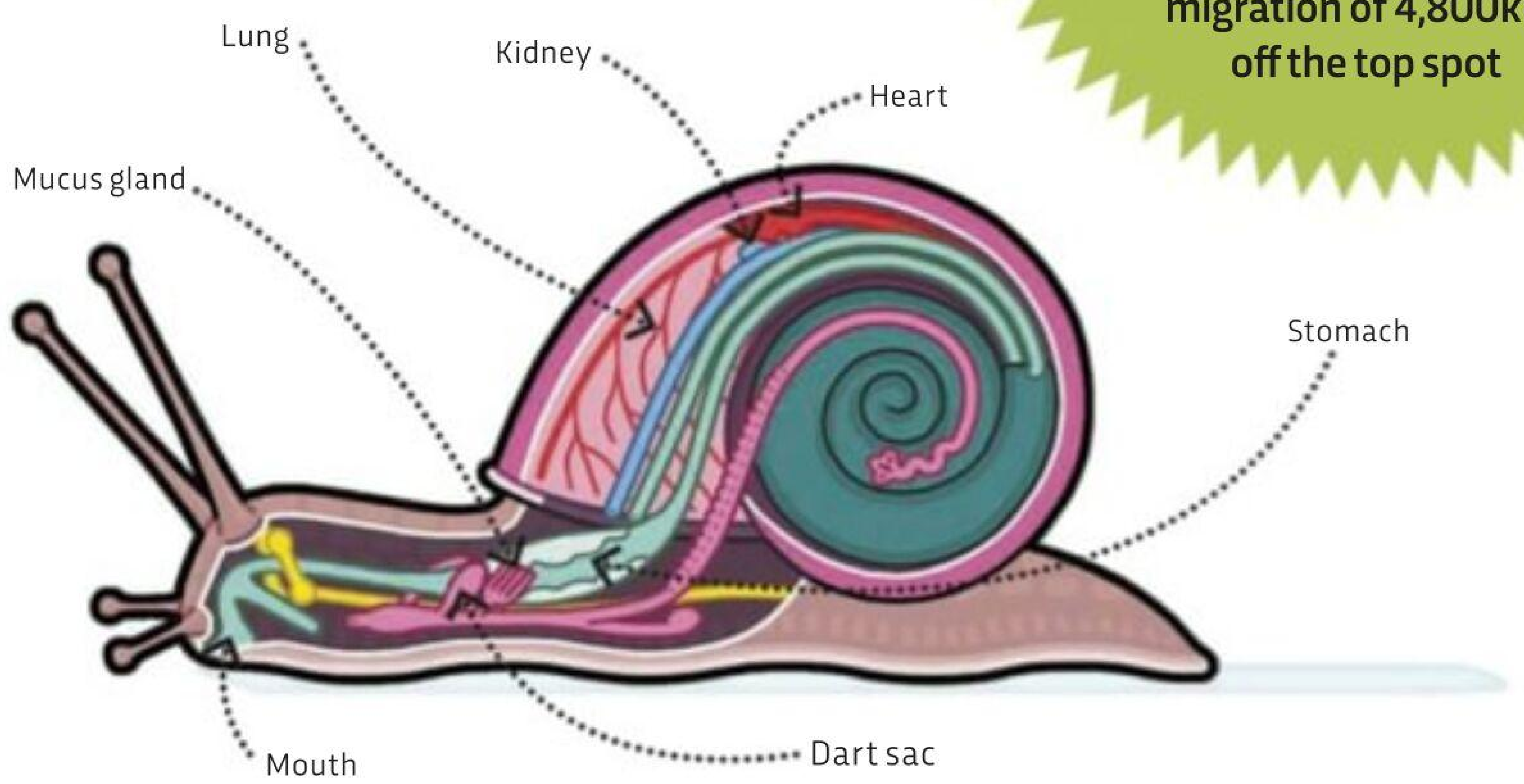
Wombats are herbivores that are specialised to eat tough roots and grasses. They have an extremely slow digestion that takes up to 14 days to complete. Sitting in the tightly packed stack of intestines for so long, the faeces form a roughly cuboid shape because it tessellates better into the available space. By the time they exit, the droppings are so dry and hard that the circular anus isn't strong enough to squeeze them into a rounded shape. ***LV***

CAN CATS SMILE?

Cats have the muscular ability to make facial expressions that resemble smiling, but it's nothing to do with happiness. Certain odours, especially pheromone-rich ones like urine, can trigger the 'flehmen response', where cats draw scent particles to the roof of their mouth to be analysed by their extra sensory receptor, the Jacobson's organ. This behaviour is characterised by curled lips, a tilted head and squinting eyes – all of which can look like smiling. Cats may also bare their teeth in a kind of grin when feeling aggressive. Positive signs of a contented cat include purring, slow-blinking, paw-kneading, head-rubbing, meowing and tail-flicking – but never smiling! ***CC***

12,000

The distance, in kilometres, that some painted lady butterflies migrate annually. This knocks monarchs, with their migration of 4,800km, off the top spot



WHY DO SLUGS AND SNAILS PRODUCE A SILVER TRAIL?

The slime trail left by slugs and snails has qualities of both a glue and a lubricant. It helps the creature glide forwards when pressure is lifted, or stick to surfaces when pressure is applied. It's made from a carbohydrate mucus and a 'hygroscopic' protein that absorbs moisture from the air, helping to prevent it from evaporating.

The slime is secreted from a gland inside its 'foot', and the chemicals it contains are also important for communication. Interestingly, the medical community is now investigating the adhesive and elastic properties of this slime, with the hope that it might lead to a synthetic glue for repairing tissue damage. ***CC***

GETTY IMAGES X2, FLPA, RAJA LOCKEY

D

Animals with flea allergies will suffer from severe itching, and may even develop a form of dermatitis after being bitten

O OTHER ANIMALS GET ALLERGIES?

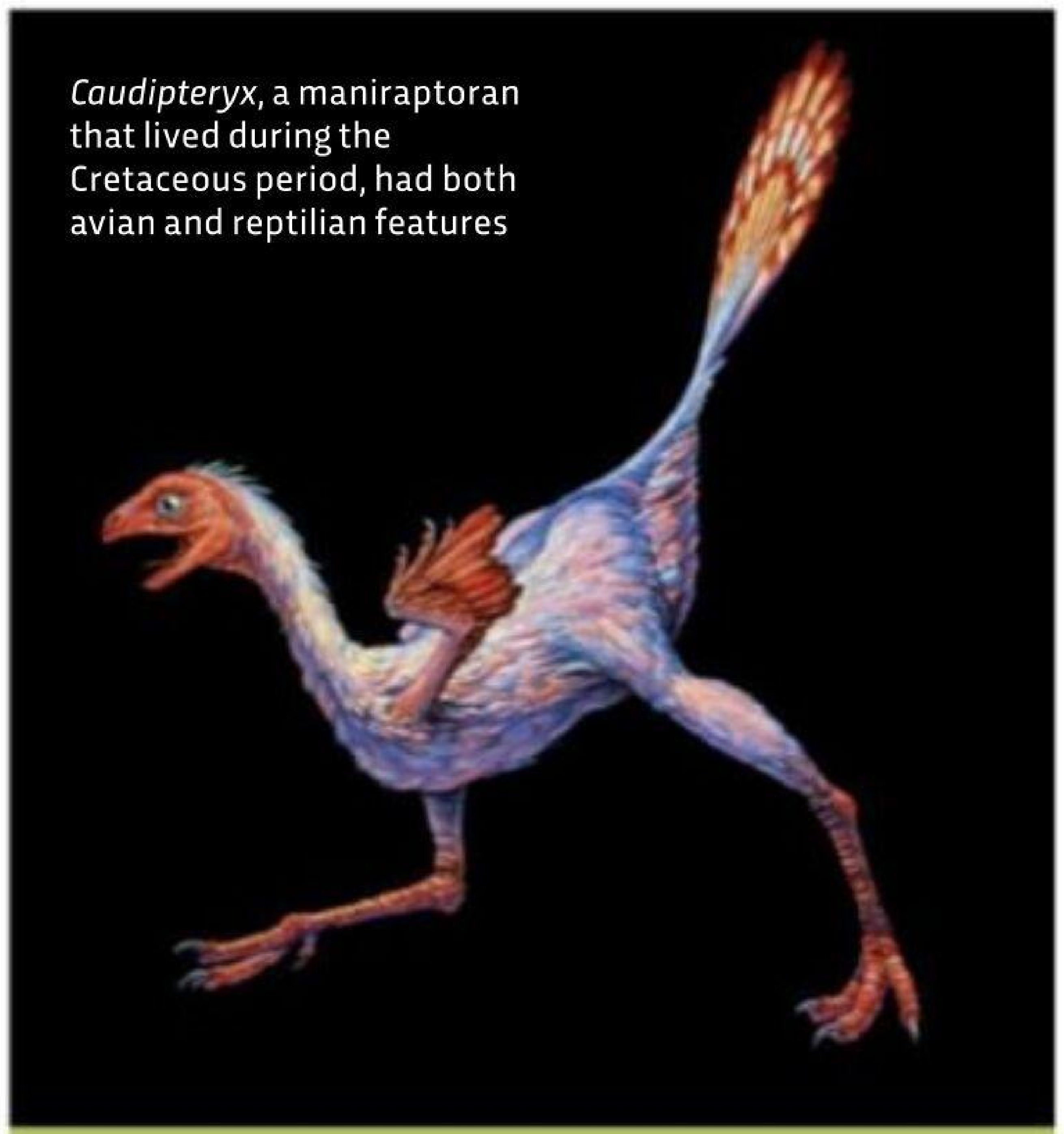
Yes. Cats, dogs and horses can all develop allergies in much the same way that humans do. There are three main kinds of allergy in animals – food, flea bites and environmental allergies, such as grass pollen and mould spores. Allergies seem to be much more common in domestic pets than in wild animals or farm animals that spend most of their time outdoors. This may be because the more hygienic conditions in human houses leave less work for the immune system and so it gets inappropriately sensitised to normally harmless particles in the environment. Animals typically get more allergic as they get older. *LV*

WHERE DO BIRDS SLEEP?

Birds usually practise 'unihemispheric' sleep, meaning that they rest one half of their brain at a time, keeping them semi-aware. But they're still at high risk of predation. Strategies to minimise the chances of being eaten include resting on water or on predator-free islands, roosting in dense shrubs or high up in trees, or hiding in cavities, such as chimneys. Birds will often opt for safety in numbers, grouping together in hundreds or even thousands. ***CC***

DO BIRDS WEE?

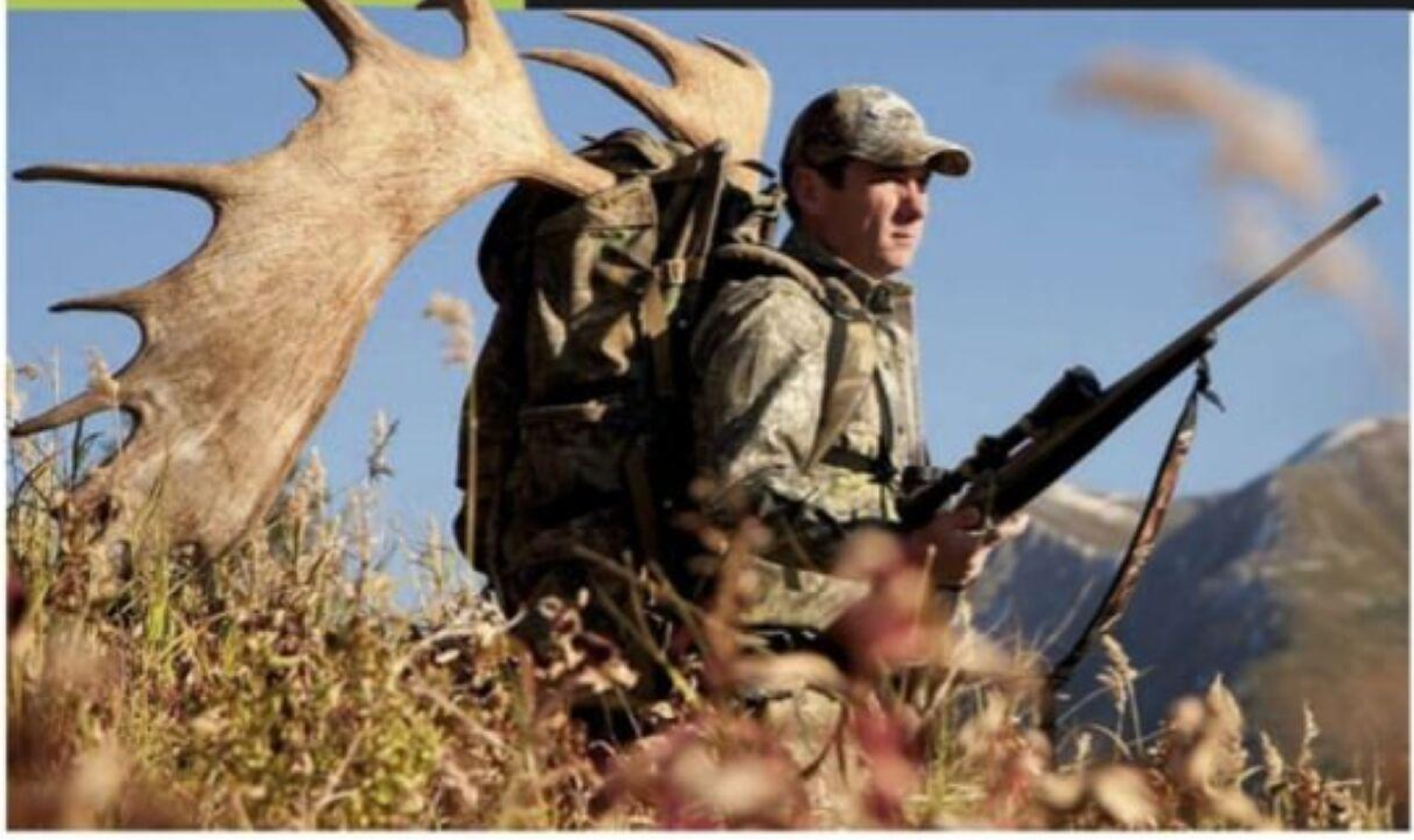
Yes, but not like we do! Birds get rid of excess nitrogen by converting it into a paste-like substance called uric acid. This is less toxic than the urea we produce, and for good reason – unhatched chicks wouldn't be able to tolerate the urea building up in their shells. Also, doing away with the need for a bladder is beneficial to birds because it reduces their load when flying. Birds have just one waste opening, the cloaca, and this is why you see the white, chalky uric acid mixed in with the dark faecal matter. ***CC***



Caudipteryx, a maniraptoran that lived during the Cretaceous period, had both avian and reptilian features

WHY WERE BIRDS THE ONLY DINOSAURS TO SURVIVE THE MASS EXTINCTION?

The asteroid that caused the extinction event at the end of the Cretaceous period struck Earth with 60,000 times the energy of the world's entire nuclear arsenal. The atmosphere would have glowed red hot for hours and all the large dinosaurs that couldn't burrow underground or hide underwater were roasted. When the smaller species came out of hiding they found a charred landscape and air so thick with soot and sulphur dioxide that sunlight was almost completely blocked out for the next year. It was too dark for photosynthesis, so the herbivores died, then the carnivores. Birds are descended from the maniraptoran dinosaurs but they had two important adaptations that helped them survive. First, they had beaks instead of teeth, which allowed them to crack open seeds and nuts buried in the topsoil. Second, their relatively large skull capacity suggests that they were more intelligent than the other reptiles. They may have lived in more complex social groups that could cooperate and adapt to find new food sources in the post-apocalyptic landscape. This allowed them to outcompete any other species of small dinosaur that might have survived the initial impact. ***LV***



HOW DOES TROPHY HUNTING AFFECT WILD ANIMAL POPULATIONS?

Since the Roman Empire, wild animals have been slaughtered to demonstrate power and wealth. Bigger is better when it comes to this 'sport', which means that dominant, mature male rhinos, elephants, lions, leopards and other animals are the prime targets of hunters. The artificially premature loss of strong, healthy individuals takes vital genes out of the breeding pool, which, over time, can result in an overall decline in body size and, where applicable, also horn or tusk size. Removing these frontline animals also undermines social cohesion and can leave members of prides and herds vulnerable to attack by other members of their own species. Although some argue that money from trophy hunting can help with conservation, there is not enough evidence to convince us that it can. ***CC***

WHY ARE CATS SCARED OF CUCUMBERS?

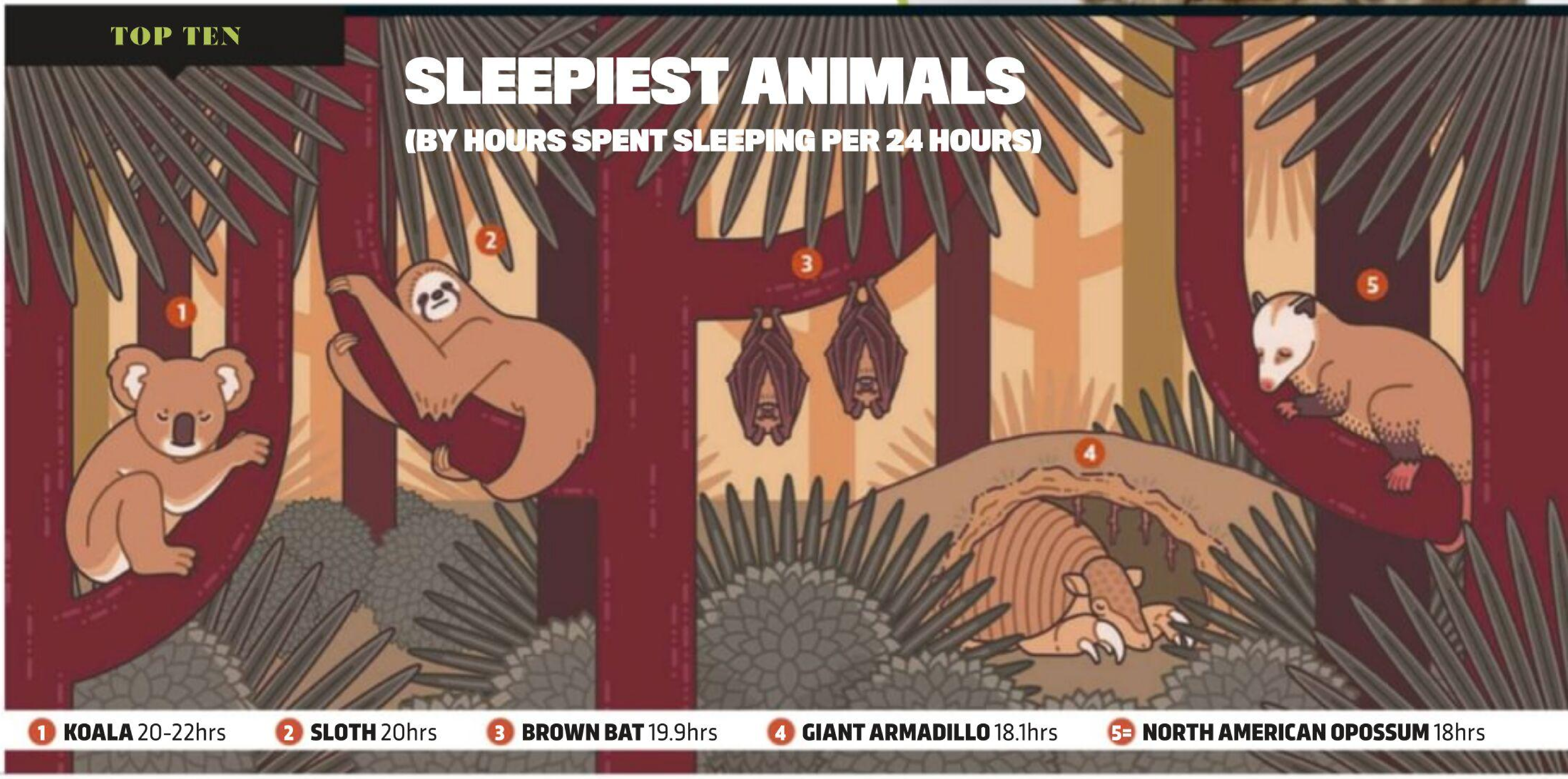
Videos of cats jumping out of their skin after suddenly spotting a cucumber have been doing the rounds online for a while now. Cats are hypersensitive to their surroundings, so it's the sudden appearance of a random object that spooks them. Cucumbers also look quite snake-like on first glance, so this may be why this vegetable provokes such an extreme reaction. Please don't try this at home, though – it's stressful for the cats! ***CC***

GETTY IMAGES X2, ALAMY, RAJA LOCKEY

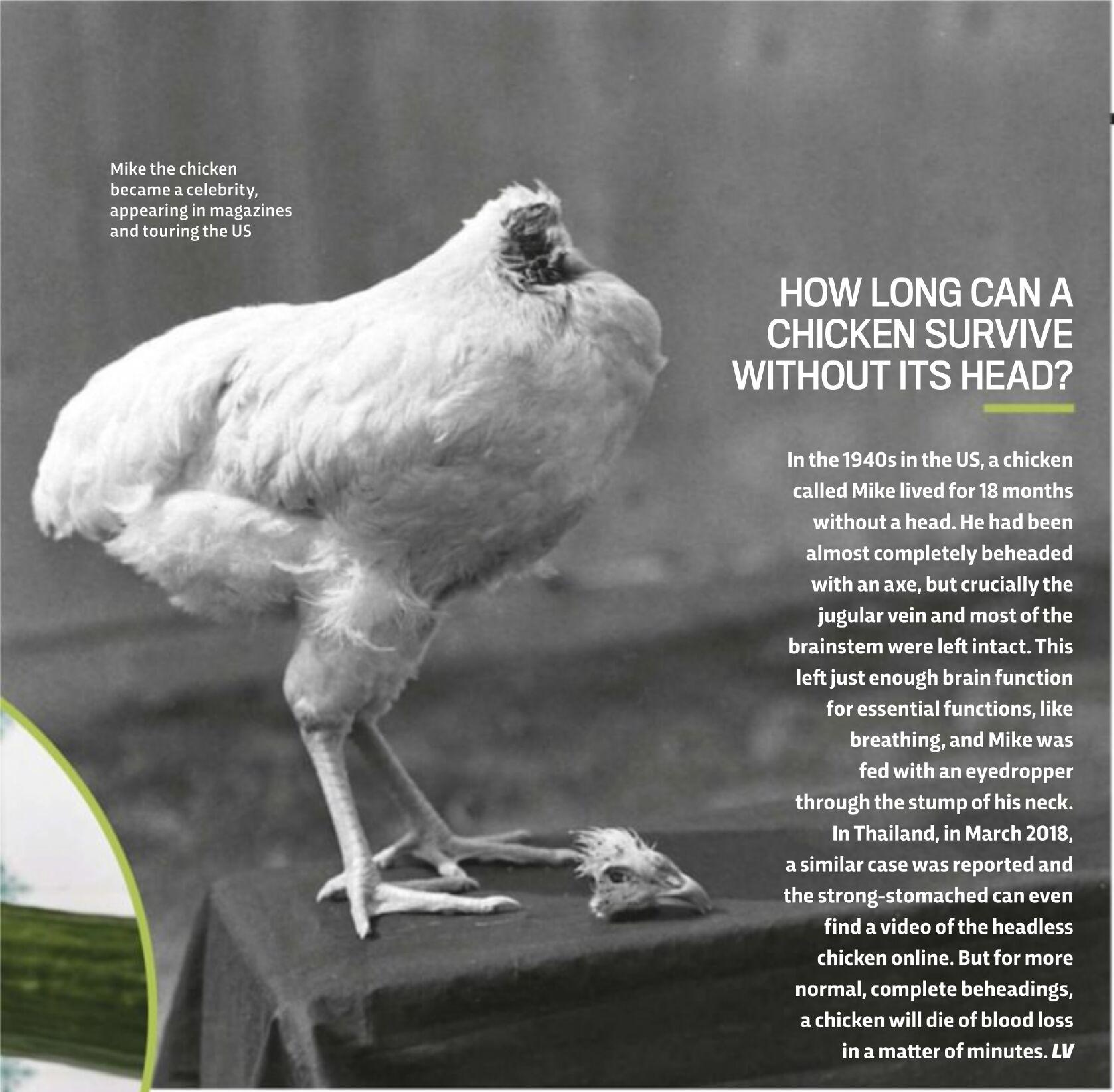
TOP TEN

SLEEPIEST ANIMALS

(BY HOURS SPENT SLEEPING PER 24 HOURS)



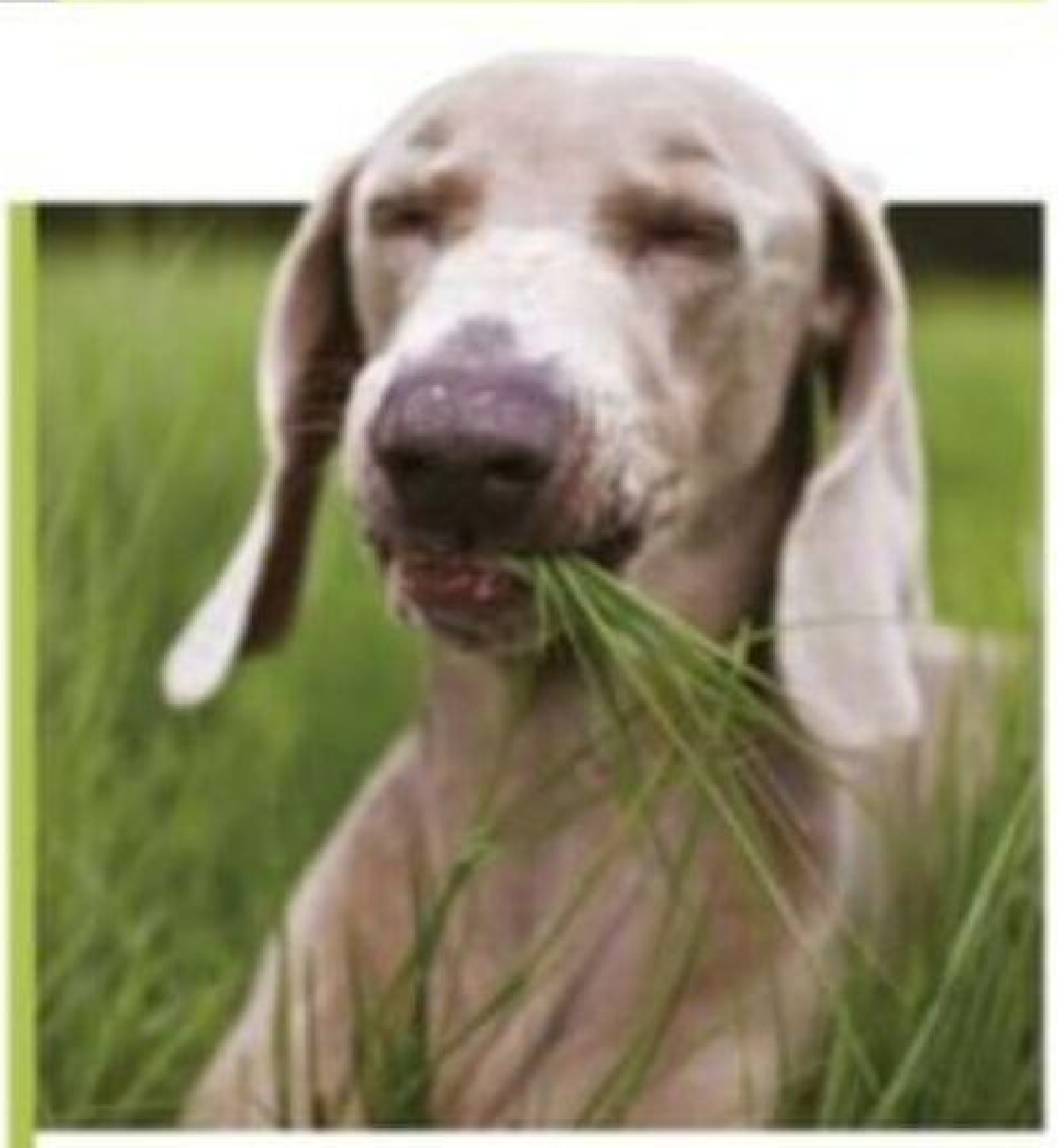
① **KOALA** 20-22hrs
② **SLOTH** 20hrs
③ **BROWN BAT** 19.9hrs
④ **GIANT ARMADILLO** 18.1hrs
5= **NORTH AMERICAN OPOSSUM** 18hrs



Mike the chicken became a celebrity, appearing in magazines and touring the US

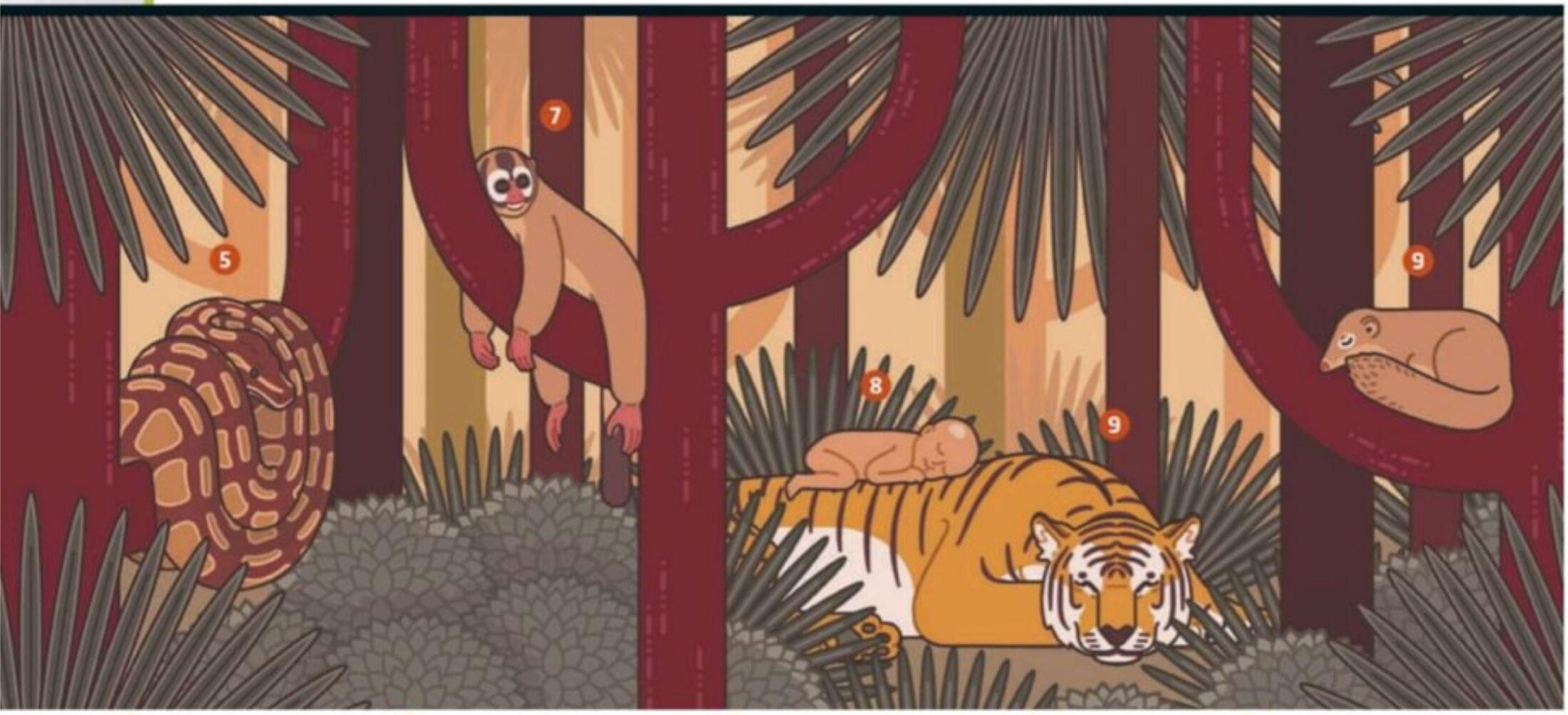
HOW LONG CAN A CHICKEN SURVIVE WITHOUT ITS HEAD?

In the 1940s in the US, a chicken called Mike lived for 18 months without a head. He had been almost completely beheaded with an axe, but crucially the jugular vein and most of the brainstem were left intact. This left just enough brain function for essential functions, like breathing, and Mike was fed with an eyedropper through the stump of his neck. In Thailand, in March 2018, a similar case was reported and the strong-stomached can even find a video of the headless chicken online. But for more normal, complete beheadings, a chicken will die of blood loss in a matter of minutes. ***LV***



WHY DO DOGS EAT GRASS?

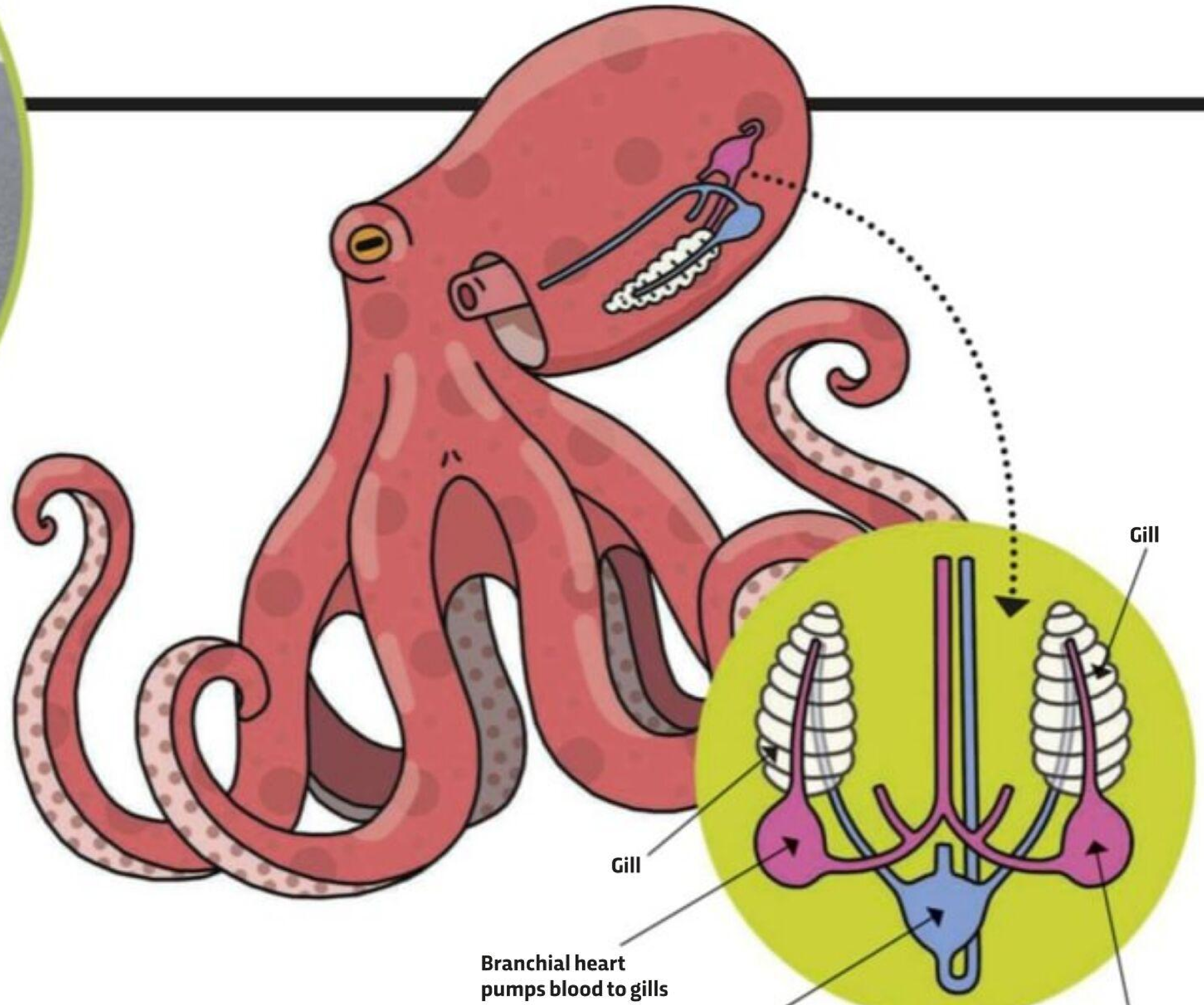
A 2008 study found that 68 per cent of dogs regularly eat grass but only 22 per cent of them are sick afterwards, so it doesn't seem to be because the dog is ill. Wolves also eat grass and it may be that this helps to purge their intestines of parasites. Dogs may have inherited this ancestral behaviour even though most pets are regularly wormed. ***LV***



5= PYTHON 18hrs **7 OWL MONKEY** 17hrs **8 HUMAN INFANT** 16hrs **9= TIGER** 15.8hrs **9= TREE SHREW** 15.8hrs

DO GUIDE DOGS KNOW THAT THEIR MASTERS ARE BLIND?

Although all dogs show signs of having 'theory of mind', which enables them to grasp the fact that we think differently from them, it's unlikely that they're capable of extending this to knowing the reason why one person behaves differently to another. The concept of vision, and therefore the loss of it, is a complex one, so we don't think dogs have an understanding of what it means to be blind. But, of course, they can learn what things a blind person needs help with and adjust their behaviour accordingly. Interestingly, studies show that guide dogs will still look to their master's face for cues when begging for food, just as a sighted person's dog would. ***CC***


Gill
Gill
Branchial heart pumps blood to gills
Systemic heart pumps blood round body
Branchial heart pumps blood to gills

HOW MANY HEARTS DOES AN OCTOPUS HAVE?

Octopuses have three hearts: one pumps blood around the body; the other two pump blood to the gills. The reason for this impressive cardiac hardware probably comes down to the unusual composition of their blood. Unlike vertebrates that have iron-rich haemoglobin packed into red blood cells, octopuses have copper-rich haemocyanin dissolved directly in their blood (so it's blue). Haemocyanin is less efficient than haemoglobin as an oxygen transporter. The three hearts compensate for this by pumping blood at higher pressure around their bodies to supply the octopuses' active lifestyles. ***HS***

WHY ARE PIGEONS SUCH A SUCCESSFUL CITY BIRD?

Pigeons arose from the domestication of rock doves 10,000 years ago. Having originated from domestic stock, it's no surprise that the UK's estimated 18 million feral pigeons are tolerant of humans. These unfussy eaters will flock to areas where people feed them, plus the tall buildings in our cities are perfect for them as they replicate the cliff faces that are still home to wild rock doves. ***CC***

Cities provide abundant roosting and feeding opportunities for pigeons

GETTY IMAGES X5, RAJA LOCKEY

HOW DO PARROTS 'TALK'?

In the wild, parrots live in flocks and they learn to copy the 'catchphrases' of their own flock, as a way of telling who belongs to the flock and who is an outsider. Scans show that parrot brains have a different structure to songbirds' brains, and this can help to explain why they're so good at vocal learning. In captivity, alone in a cage, the only vocalisations available to parrots are human speech, so they naturally learn to imitate this instead. ***CC***

WHY DO OYSTERS MAKE PEARLS?

It's an immune response designed to protect the oyster from a parasite or an injury (not just a grain of sand as is commonly believed). Cells from the mantle of the oyster form a pearl sac around the irritation. The pearl sac then secretes calcium carbonate and conchiolin protein that builds up in layers to form an impermeable barrier. *LV*

The grey-headed flying fox is one species of bat that does not echolocate. It relies on sight and smell to find its food

IF BATS ARE BLIND, WHY DO THEY HAVE EYES?

Despite the famous idiom, bats aren't blind. All bats rely on sight to find food, avoid predators and navigate to and from roosts. As expected in a nocturnal mammal, their eyes are heavily loaded with photoreceptor cells called rods, which maximise their ability to see in the dark. At night, however, most bats use echolocation to find prey – sending out ultrasonic sound waves and listening for the echoes. So bats can 'see' with both their eyes and their ears. ***CC***

Ants look highly organised when they're on the march, but they're just following their noses

WHY DO ANTS WALK IN A LINE?

Ants are highly social insects, thriving in colonies of millions of individuals that work as a team. Good communication skills lie at the heart of their success. They rely heavily on chemical scents, called 'pheromones', to defend territories and exchange complex information – from the location of food sources and nest sites, to the presence of predators. Each ant species has its own chemical vocabulary of up to 20 different pheromones, which can be secreted to form specific scent trails. The tips of their antennae translate the chemical 'words', thereby guiding the ants, in a line, to or from the desired destination. ***CC***

52,800

The mass, in tonnes, of dung produced annually by Africa's hippos – that's roughly the same mass as the *Titanic*

CAN I RAISE MY DOG OR CAT AS A VEGAN?

It's theoretically possible for dogs, but difficult. Dogs have lived with humans for at least 14,000 years and have evolved some extra digestive enzymes that help them to digest plant starches, probably due to sharing our food. But a 2015 study at the University of California, Davis, found that 25 per cent of commercial vegetarian dog foods lacked the right balance of essential amino acids. And homemade diets are worse: a 1998 study found that 50 per cent of dogs fed homemade vegetarian or vegan food had dietary deficiencies. For cats, it is even harder. Cats are entirely carnivorous in the wild, and there are several amino acids only found in meat, such as taurine, that they can't synthesise or store, so a vegan cat diet has to be tailored to their age and body weight. Too little taurine can cause blindness and heart failure, while too much can lead to urinary tract infections. Carnivorous cats absorb all the taurine they need from meat, but synthetic taurine added to vegan food comes in many different forms, which are absorbed at different rates. This makes it very difficult to give cats a balanced vegan diet. ***LV***

HOW FREE-RANGE ARE FREE-RANGE CHICKENS?

UK regulations require free-range poultry to have access to the outside during daylight hours via 'popholes'. Each bird needs to have at least 4m^2 of outside space. The indoor barn where the birds perch and lay eggs can have up to nine birds per square metre. EU organic standards require lower densities of six birds per square metre in the barns, and maximum flock numbers of 3,000 birds. Under certain organic standards, beak trimming is not permitted, but this is allowed with free-range hens. ***LV***

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PROTODUNE,
FRENCH-SWISS BORDER

What is this?

Bathed in yellow light to avoid overstimulating its sensors, this neutrino detector is the size of a three-storey house. Trillions of neutrinos pass through you every second but they hardly interact with matter, so they're tough to detect. When in operation, ProtoDUNE is filled with 800 tonnes of liquid argon. When a neutrino hits an argon nucleus it produces a trail of charged particles that the detector can pick up.

This prototype is being tested at CERN's HQ, but DUNE (Deep Underground Neutrino Experiment) will be buried 1.5km underground in the disused Homestake gold mine in Lead, South Dakota.

MAXIMILIEN BRICE/CERN

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COULD WE GET ANTIGRAVITY FROM ANTIMATTER?

As its name suggests, antimatter is a kind of mirror image of ordinary matter, made up of particles like positrons, with the opposite charge and spin to electrons. ('Spin' is a type of angular momentum that all subatomic particles have, spin can have a value of ½ or 1.) But most theorists doubt that antimatter also produces antigravity. That's because the so-called charge-parity-time (CPT) theorem of quantum theory suggests antimatter's 'anti-ness' does not extend to its mass and gravitational effect. That said, it's always possible there's a loophole in this theorem: it's had to be tweaked several times over the decades to explain newly discovered phenomena. In 2018, experimentalists at CERN, home of the Large Hadron Collider, were planning to begin looking for signs of strange behaviour when particles of antimatter are released in a vacuum. If the particles rise, antigravity may be the explanation. ***RM***

Inside the Large Hadron Collider at CERN is where scientists hope to unravel the mysteries of antimatter

MATHS & PHYSICS

ANTIMATTER, QUANTUM EFFECTS, PRIME NUMBERS, GRAVITATIONAL WAVES, TIME, THE HIGGS BOSON AND NUCLEAR FISSION...

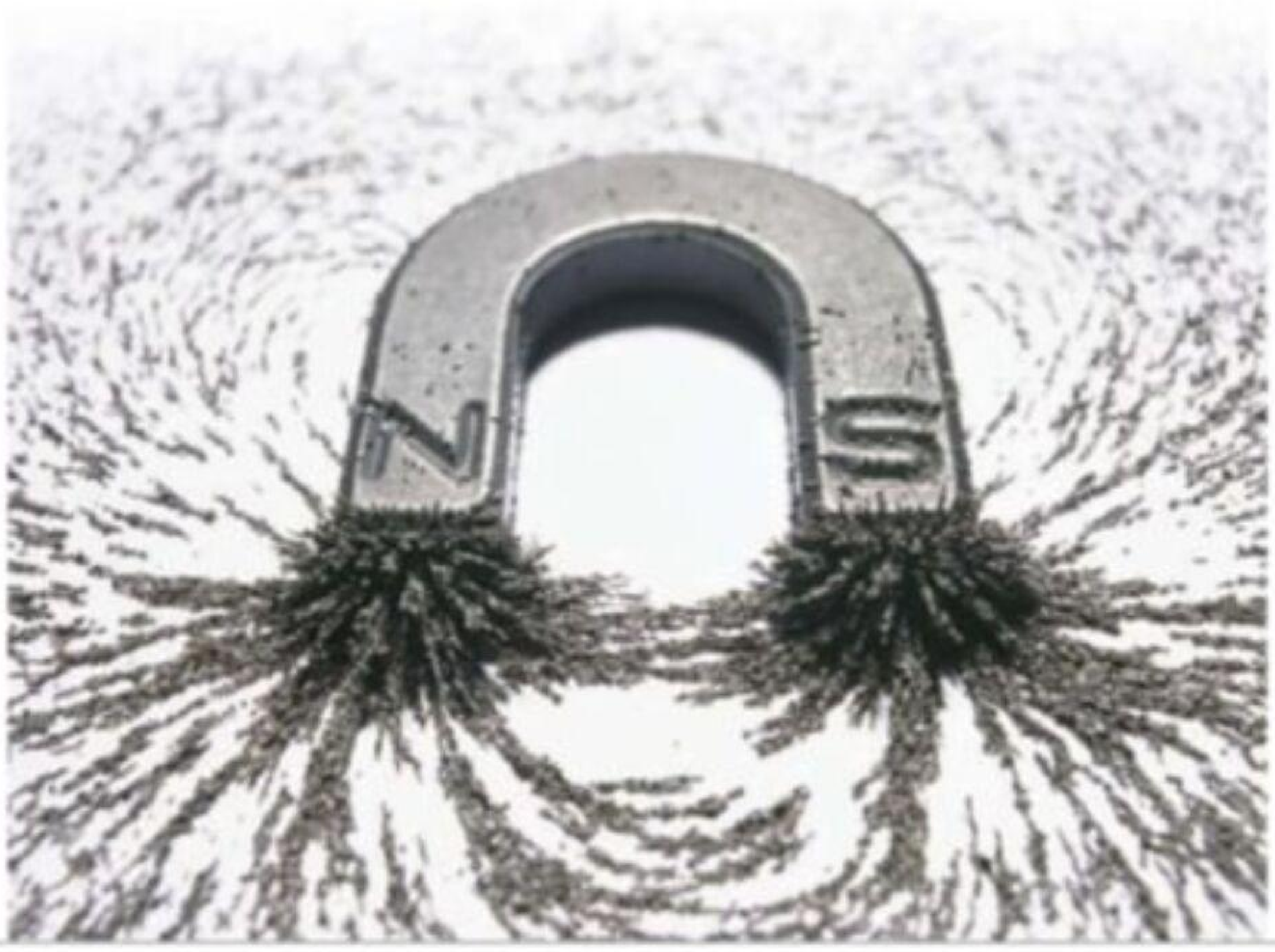
DOES IT TAKE MORE EFFORT TO SWIM IN THE DEEP END OF A POOL THAN THE SHALLOW END?

When swimming, water generates drag forces from three sources: friction from the 'stickiness' of water, waves created on the surface, and resistance to pushing through the water. Unless the water is so shallow that the chest of the swimmer takes up a sizeable fraction of the total depth, these sources of drag are the same for shallow or deep water, so that swimming will require the same amount of effort. ***RM***

GETTY IMAGES X3

ARE THERE ANY QUANTUM EFFECTS THAT WE CAN SEE DAY TO DAY?

As they govern the behaviour of atoms, quantum effects underpin everything from the ability of plants to turn sunlight into chemical energy to the behaviour of semiconductors in microchips. Perhaps the most spectacular demonstration of quantum effects, pure and simple, is a magnet. Despite its familiarity, magnetism is actually impossible without quantum effects, which are needed to explain the necessary behaviour of atoms. For example, the ability of a simple bar magnet to pick up a needle is the result of the so-called Pauli Exclusion Principle, a key component of quantum theory that dictates how electrons are arranged. ***RM***



IS THERE ANY POINT TO FINDING EVER-BIGGER PRIME NUMBERS?

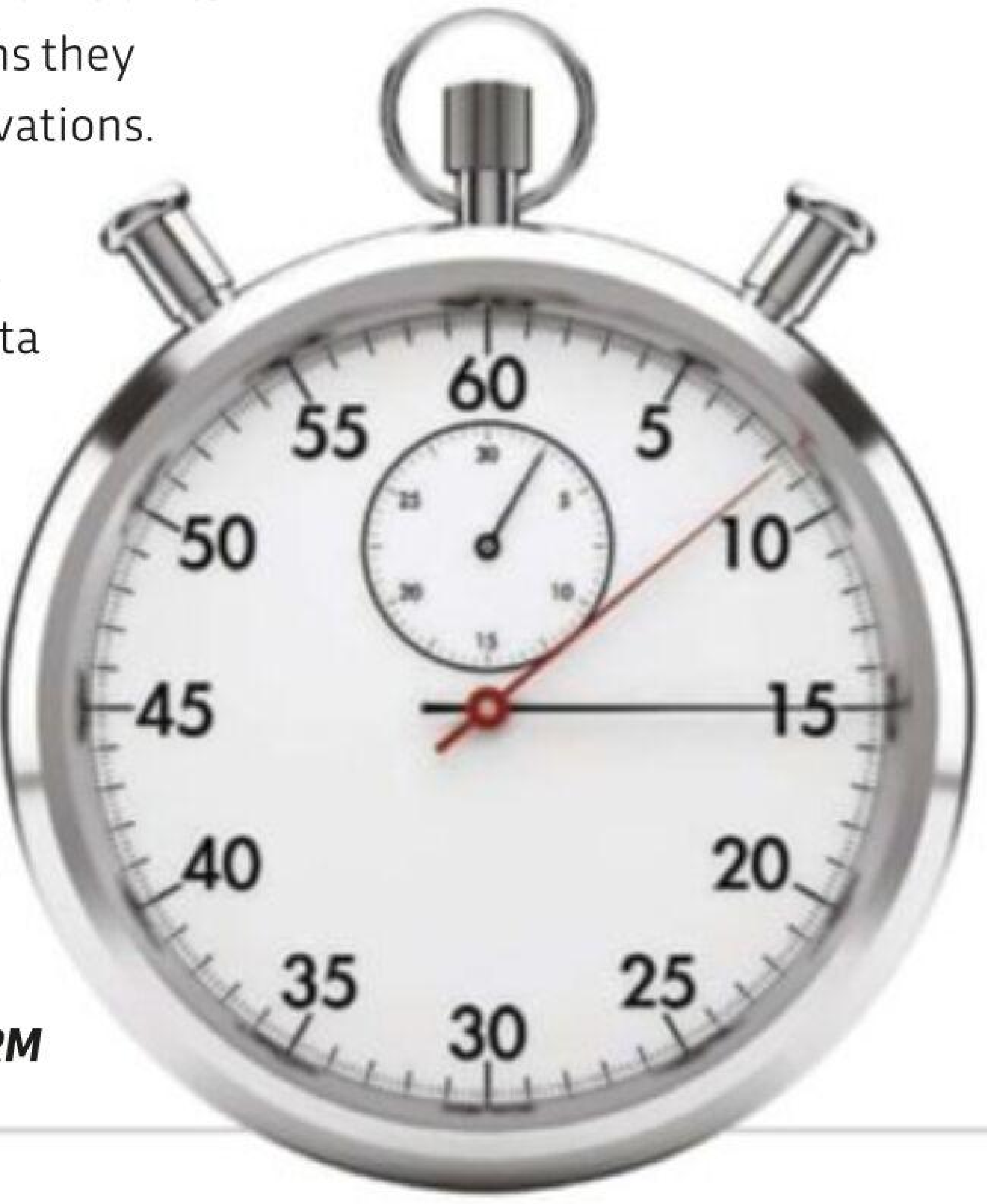
The largest prime number yet found – code-named M8289933 – is over 24 million digits long and was found by a member of a global team of computer enthusiasts. But apart from brief fame and a cheque for $3,000, there seems little point, as even the Ancient Greeks knew that there's an infinite number of them. The only practical value comes from using the search algorithms to give new computer hardware a workout. ***RM***

WHY CAN'T WE FEEL ATMOSPHERIC PRESSURE?

The Earth's atmosphere is bearing down on all of us with a pressure at sea level equivalent to around 10 tonnes of weight per square metre. So simply standing upright means carrying the weight of a small car. The reason we can't feel it is that the air within our bodies (in our lungs and stomachs, for example) is exerting the same pressure outwards, so there's no pressure difference and no need for us to xert any effort. ***RM***

HOW WAS THE LENGTH OF A SECOND FIRST CALCULATED?

The Babylonians focused on the major time units of years, days and hours, whose lengths they determined using astronomical observations. But the invention of the first clocks in medieval times allowed finer division. These were named in Latin: pars minuta prima – 'the first very small part' (the minute); and pars minuta secunda – 'the second very small part' (the second). Following the tradition of the Babylonians, these divisions were expressed in the sexagesimal system, a form of counting based on units of 60, so a second became a 60th of a 60th of an hour, leading to its definition as 1/3600th of an hour. ***RM***



WHAT WOULD HAPPEN IF A VERY STRONG GRAVITATIONAL WAVE PASSED THROUGH US?

Gravitational waves spread out from any violent event involving matter – such as, for example, the collision of two black holes. Like gravity, however, gravitational waves are incredibly weak, so you'd have to be extremely close to their source in order to feel their effects. Experiencing a gravitational wave would definitely feel weird, though – they create a rhythmic stretching and squashing sensation on the body. But you'd have to be so close to the cataclysm itself that you'd never live to describe it. ***RM***

HAS THERE EVER BEEN A SMALL HADRON COLLIDER?

The Large Hadron Collider (LHC) has made headlines with its unprecedented power to probe the nature of matter. But the LHC is the culmination of decades of research into ways of smashing together subatomic particles with ever greater violence. In the 1960s, physicists began investigating ways of boosting the energy of particle collisions by running two beams of

WAS MATHS INVENTED OR DISCOVERED?

The fact that 1 plus 1 equals 2, or that there's an infinite number of primes, are truths about reality that held even before mathematicians knew about them. As such, they're discoveries – but they were made using techniques invented by mathematicians. For example, according to Pythagoras' theorem, the square of the hypotenuse of a right-angled triangle is equal to the sum of the squares of the other two sides. This is true for all right-angled triangles on a level surface, so it's a discovery. Showing it is true, however, requires the invention of a proof. And over the centuries, mathematicians have devised hundreds of different techniques capable of proving the theorem. In short, maths is both invented and discovered. ***RM***

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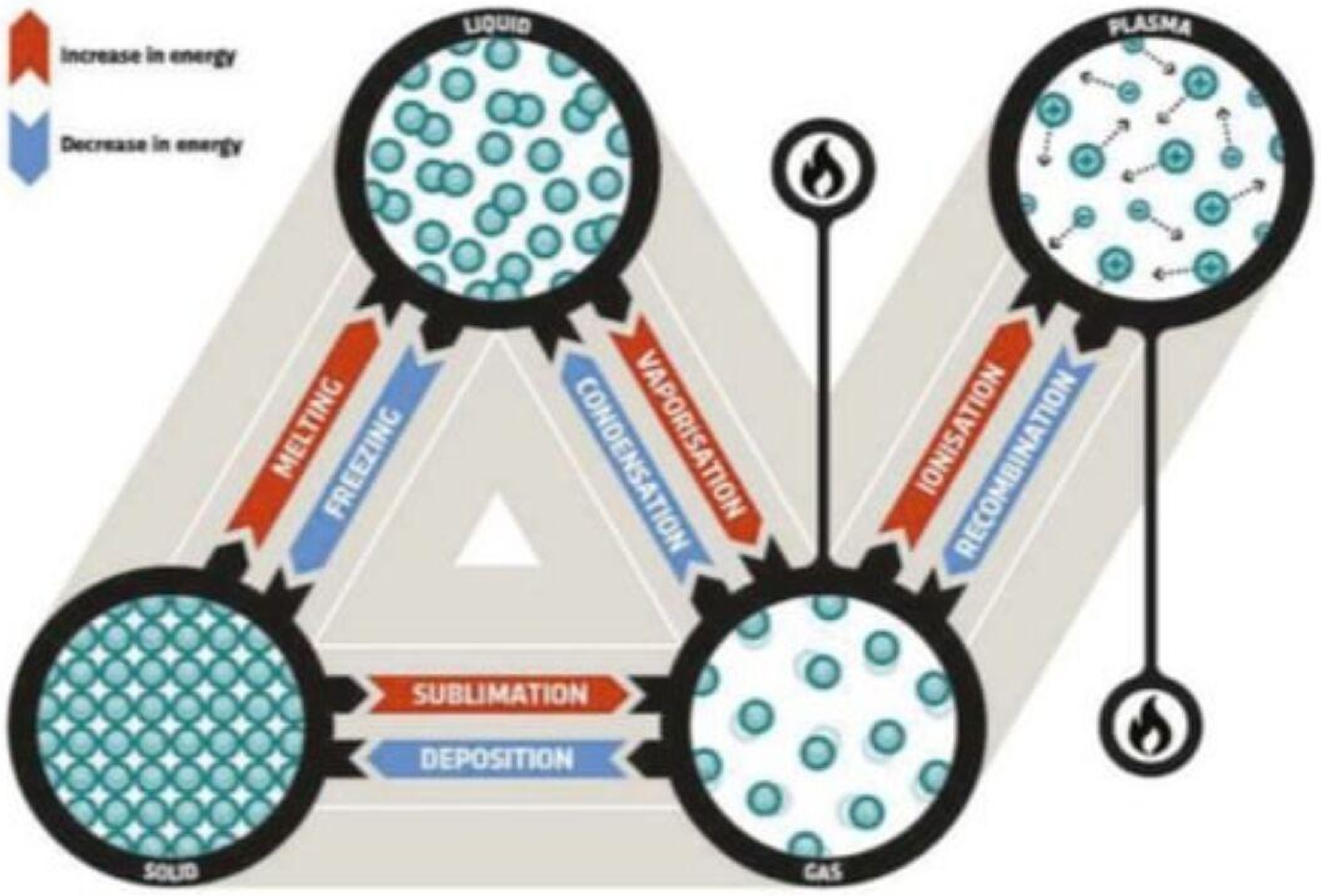
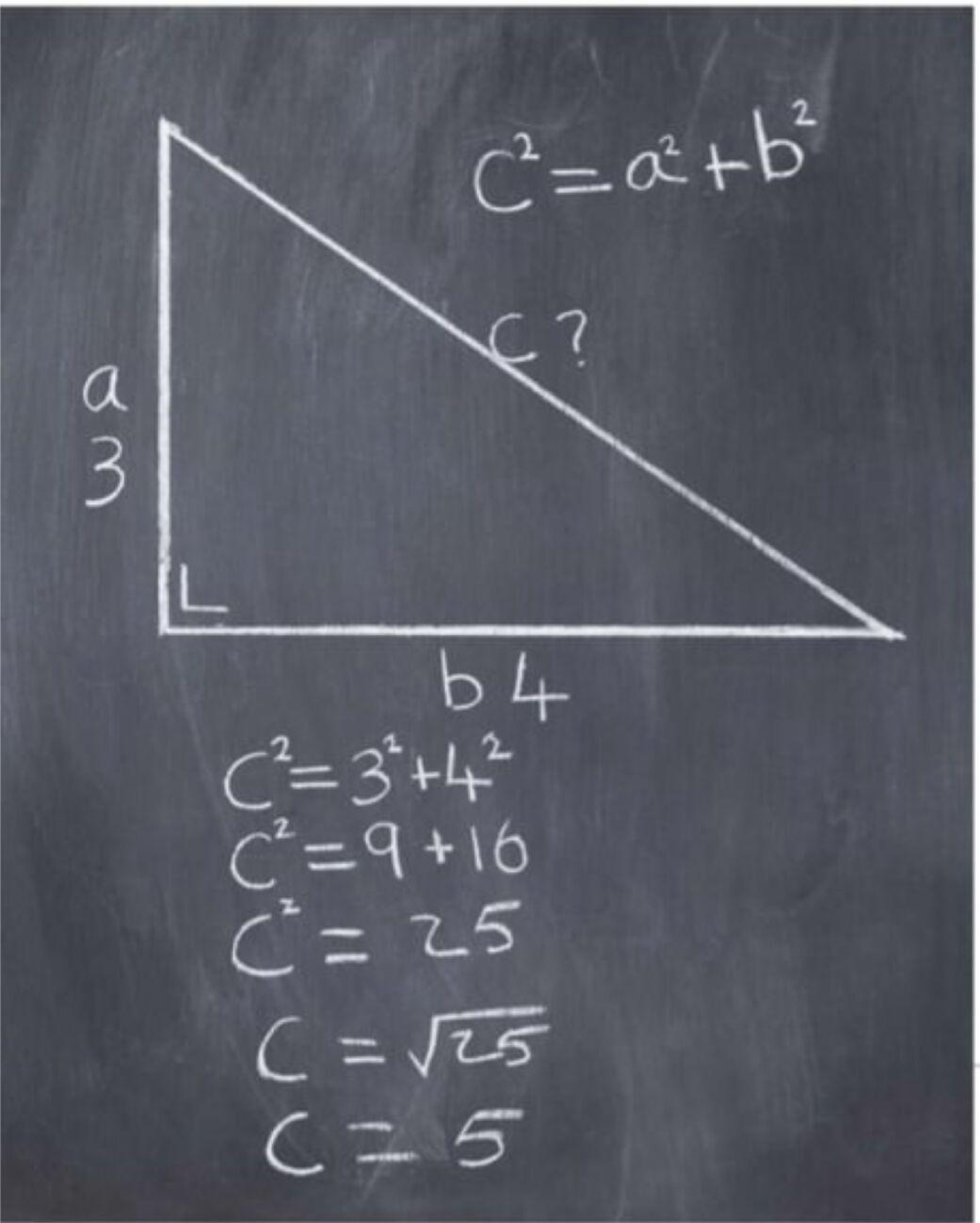
particles into each other, rather than simply smashing one beam into a stationary target. In 1970, scientists at CERN near Geneva unveiled the Intersecting Storage Rings (ISR), which used magnets to accelerate and then bring together two streams of protons (particles belonging to the family known as 'hadrons'). It was the world's first hadron collider. Despite being just 150m across, the design of the ISR boosted the impact energy 30-fold compared to hitting a fixed target. Over 30 years later, the same basic idea was incorporated into the LHC, which is over 8.5km across and achieves energies 200 times greater still. ***RM***


Increase in energy
Decrease in energy
LIQUID
PLASMA
MELTING
FREEZING
VAPORISATION
CONDENSATION
IONISATION
RECOMBINATION
SUBLIMATION
DEPOSITION
SOLID
GAS

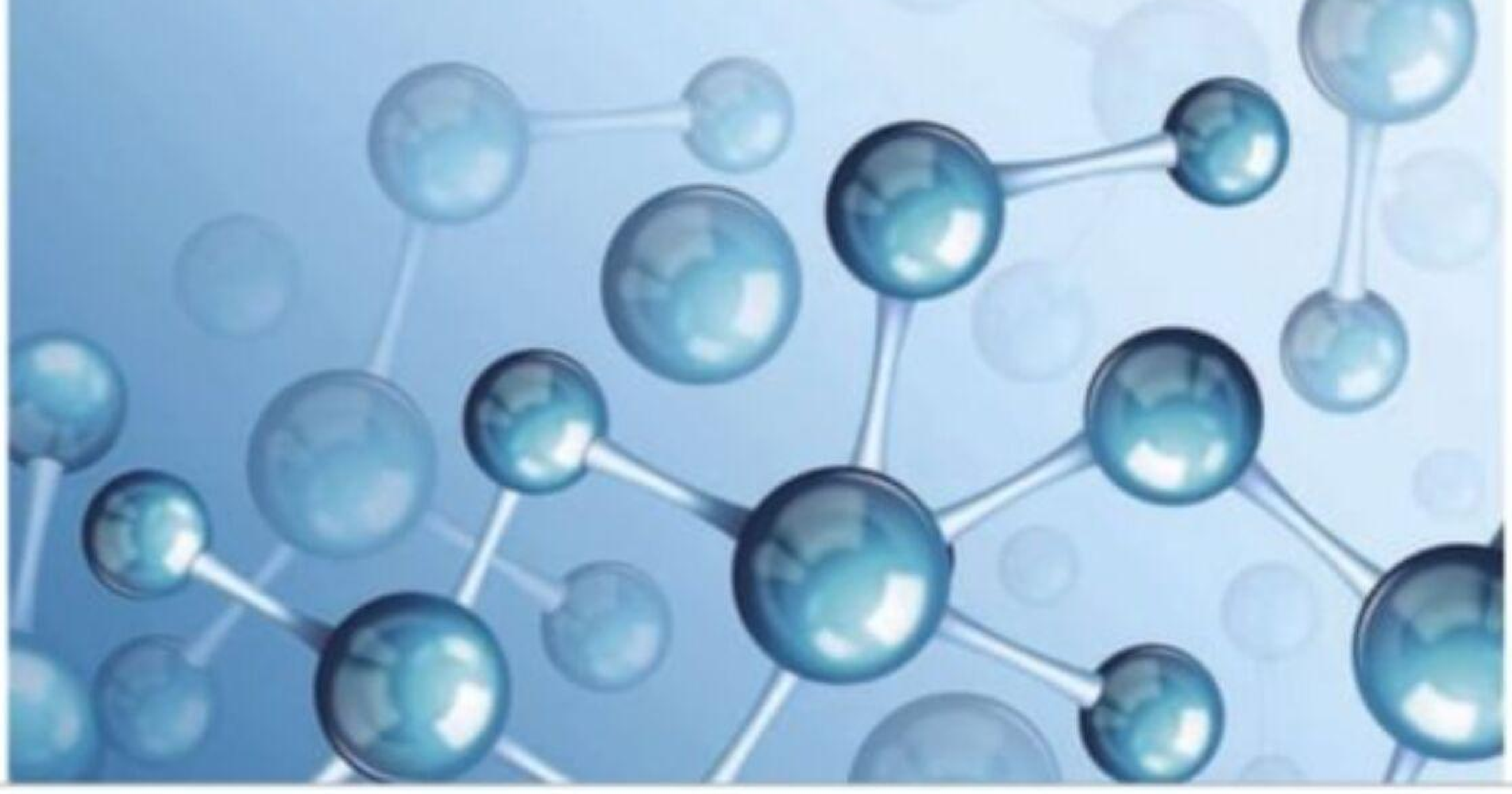
WHAT STATE OF MATTER IS FIRE: SOLID, LIQUID OR GAS?

The nature of a flame depends on what is being burnt. A candle flame will primarily be a mixture of hot gases (air and vaporised paraffin wax). The oxygen in the air reacts with the paraffin to produce heat, light and carbon dioxide. Other materials – such as magnesium – burn much hotter, resulting in the fourth state of matter: plasma. ***ML***


$c^2=a^2+b^2$
c?
a
3
b 4
$c^2=3^2+4^2$
$c^2=9+16$
$c^2=25$
$c=\sqrt{25}$
$c=5$

ARE ATOMS EXPANDING AS THE UNIVERSE EXPANDS?

The expansion of the Universe only significantly affects space and time on scales bigger even than entire clusters of galaxies. Below this, the size of objects is dictated by far stronger influences, notably the force of electromagnetism in the case of atoms. Extremely sensitive measurements have found no evidence that the fundamental properties of atoms are anything other than constant. ***RM***



DO TWO MIRRORS FACING EACH OTHER PRODUCE INFINITE REFLECTIONS?

It's always fun to look at the multiple reflections formed by opposing mirrors in lifts, washrooms and the like. But while they seem to extend into the infinite, in reality they get progressively darker and fade into invisibility long before they get there. That's because mirrors absorb a small fraction of the energy of the light striking them each time. Thus, even the best mirrors are unlikely to generate more than a few hundred visible reflections. *RM*

WHY ARE SOME MATERIALS MAGNETIC?

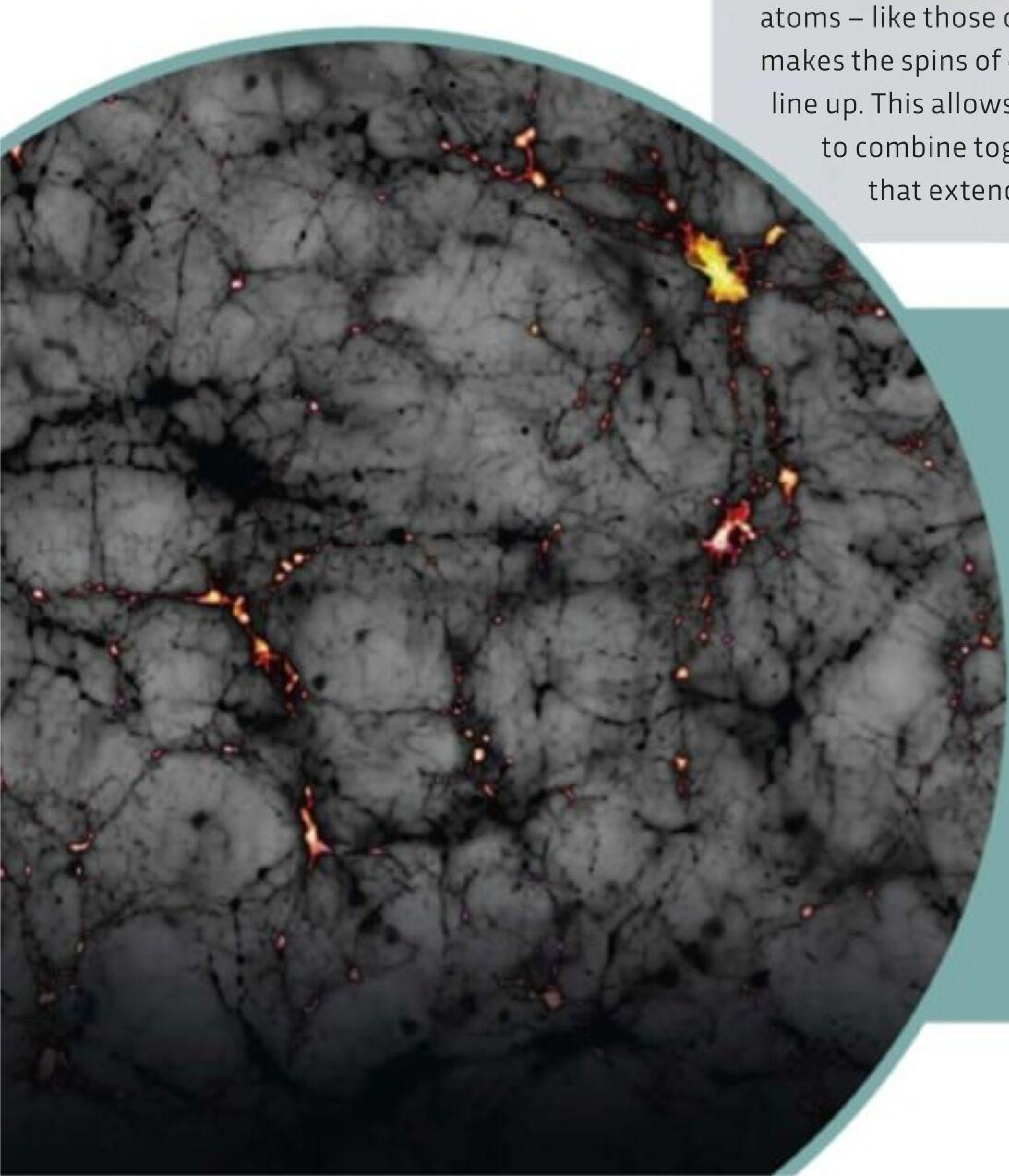
It's the result of the motion of electrons inside atoms. When electrons move through a wire, the resulting current generates a magnetic field. Electrons inside atoms are also moving: they orbit the central nucleus of atoms, and spin on their axes. In most atoms, the resulting magnetic effect is weak. But in some atoms – like those of iron – a kind of subatomic force makes the spins of electrons of neighbouring atoms line up. This allows their individual magnetic fields to combine together, producing a magnetic field that extends beyond the atoms. ***RM***

HOW SMALL WOULD THE EARTH HAVE TO BE FOR US TO FEEL IT SPINNING?

You feel a merry-go-round spinning because its radius is so small that the centrifugal force varies noticeably across the length of your body. Earth would have to be so small that your own height is a significant part of the planet's radius. Long before we got to that point, though, the Earth would have come apart due to its own centrifugal force. ***LV***

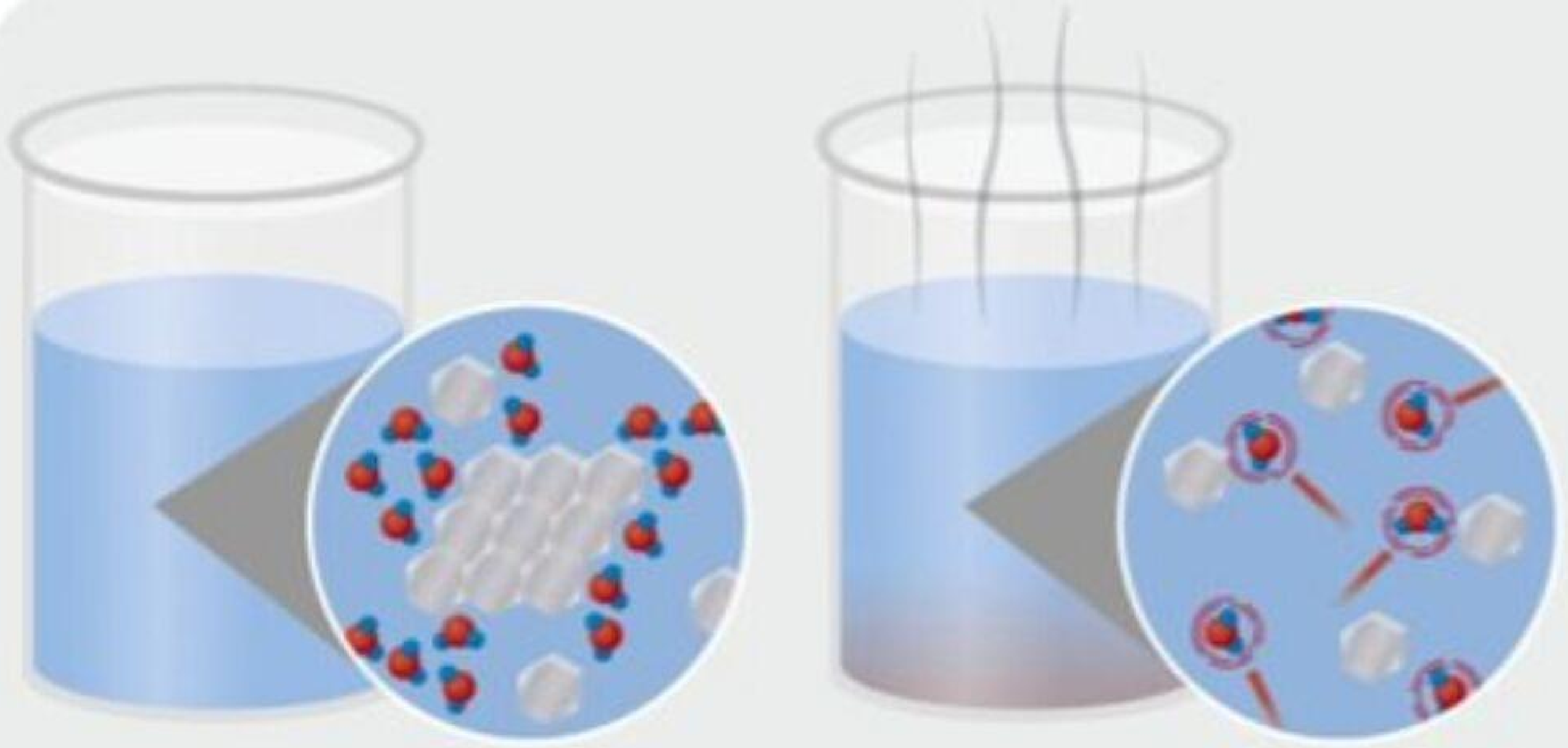
16

The number of people killed by lightning in the USA in 2017. It's a new record low – the previous record (23) was set in 2013. The fatalities by lightning have been slowly declining since data on them started being collected in the 1940s



WHAT IS EXOTIC MATTER?

It's the generic name physicists give to matter with weird properties. Exactly how weird depends on the area of physics. For example, those working in cryogenics – the study of ultra-cold temperatures – work with so-called superfluids, isotopes of helium whose quantum properties allow them to defy gravity, escaping from containers by creeping up and over the walls. But the oddest forms of exotic matter are those investigated by cosmologists, such as so-called dark matter. This is widely considered to pervade galaxies and is thought to be some form of exotic particle quite unlike the protons, neutrons and electrons making up standard matter. ***RM***



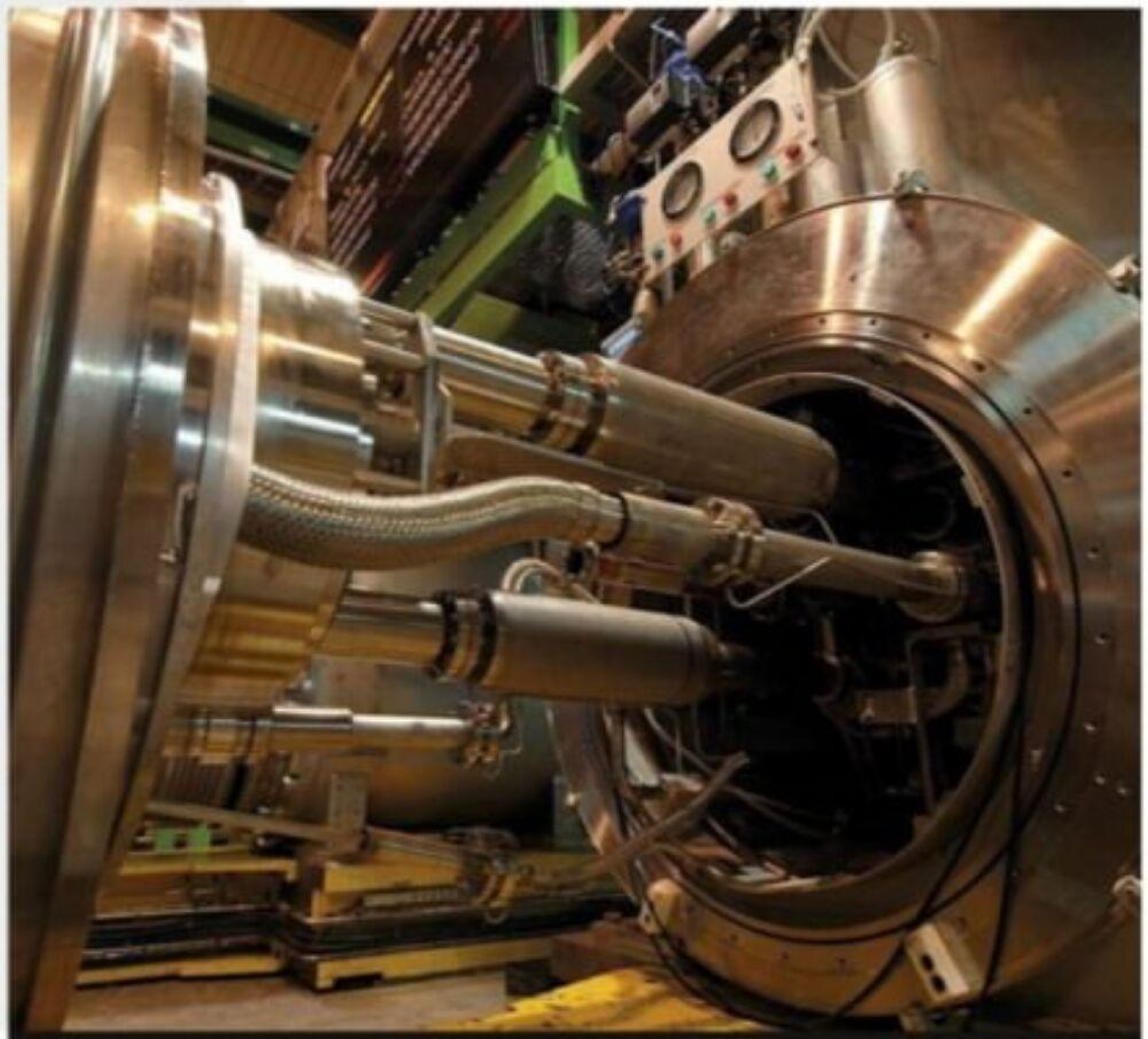
WHY IS HOT WATER A BETTER SOLVENT THAN COLD WATER?

In hot water, molecules are moving around more, so there are more collisions between the water molecules and a solid

A solvent is a substance that can dissolve other substances – water is a good solvent. Dissolving a solid requires energy input to disrupt the forces holding the molecules together, both in the solid and the water. Most solids, including sugar and salt, become more soluble with increasing temperature. This is because heat increases molecular movement, causing more collisions between the water molecules and the solid. But the opposite is true for gases, which tend to become less soluble as a solvent's temperature increases. As the gas molecules become more active, they can break free from the liquid, which explains why drinks soon lose their carbon dioxide fizz on a hot day. *ED*

WHAT'S THE SIMPLEST UNSOLVED PROBLEM IN MATHS?

If by 'simplest' you mean easiest to explain, then it's arguably the 'Twin Prime Conjecture'. Even kids can understand it, but proving it has so far defeated the world's best mathematicians. Prime numbers are the building blocks from which every whole number can be made. All numbers are thus either prime themselves, or can be made from a unique combination of primes multiplied together. When the prime numbers are written down (2, 3, 5, 7, 11, 13, 17 and so on) two patterns emerge. First, they become rarer: while 25 per cent of numbers between 1 and 100 are prime, this falls to five per cent between 1 and a billion. But while they thin out, there still seems to be an endless supply of 'twin primes' like 3 and 5, 29 and 31, 41 and 43, which differ by two. Over 2,300 years ago, the Greek mathematician Euclid proved that primes go on forever. So it seems possible that twin primes might too. That's not proof, however. Currently, all that mathematicians have managed to prove is that there's an infinite supply of primes differing by no more than 246. ***RM***



WHAT NEW INSIGHTS HAS THE HIGGS BOSON GIVEN US?

The discovery of the Higgs boson in 2012 led to global headlines and the award of Nobel Prizes to, among others, the British theorist Peter Higgs. He was one of a small group who argued that the particle was essential for explaining that most basic property of matter: mass. The Higgs is linked to an all-pervasive energy field that makes particles behave as if they have mass. Since its discovery, experiments at the Large Hadron Collider (LHC) at CERN have probed the properties of this bizarre particle. So unstable it's never been directly observed, the Higgs decays into other particles and studying these could give new insights into the forces of nature. According to current theories, the Higgs can decay into at least eight different pairs of particles. Yet the most common outcome – two so-called bottom quarks – has proved the hardest to confirm. That gave hope that something unexpected might be found. But the LHC team has recently announced they've detected the decay into bottom quarks – and it's right in line with the Standard Model (the theory that classifies elementary particles and describes three of the four known fundamental forces). Physicists are far from delighted, however. They were hoping to get glimpses of radical new phenomena, but as yet nothing has turned up. *RM*

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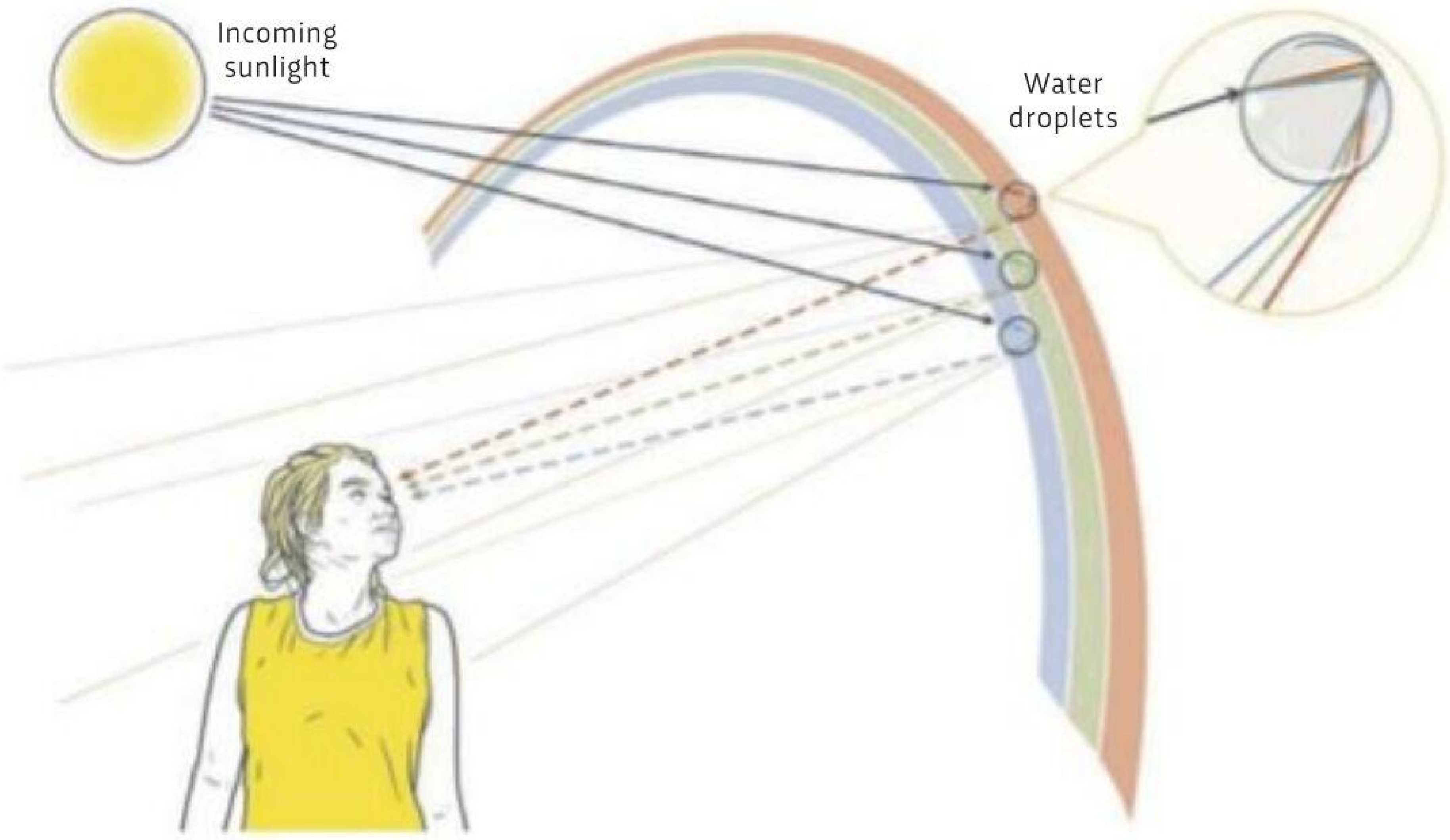
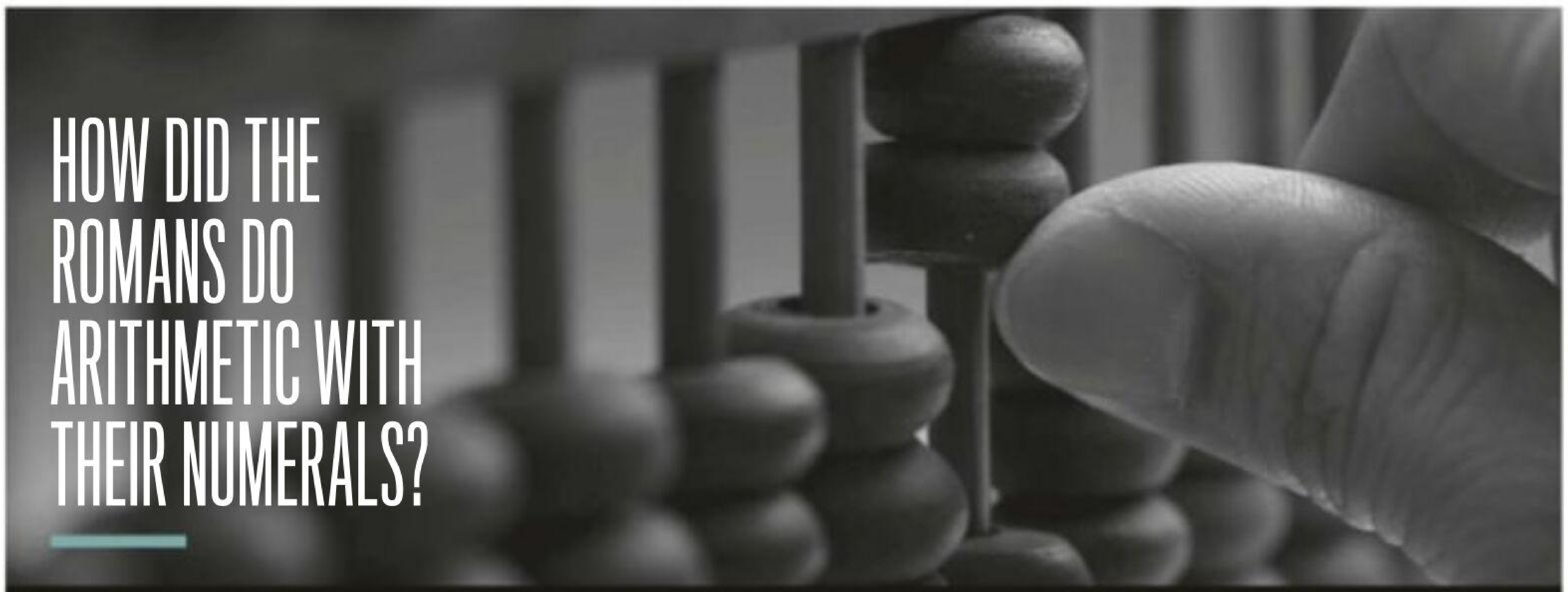
CAN WEATHER FORECASTERS PREDICT RAINBOWS?



A rainbow is created when sunlight splits into various colours as it enters raindrops. These rays then bounce off the interior and re-emerge at slightly different angles, depending on their colour. Seeing a rainbow thus depends on where you're standing relative to the Sun and the raindrops. So while forecasters can predict the conditions of patchy cloud and showery conditions that make a rainbow likely, they can't tell if you'll be in just the right place to see one. ***RM***

IF ENERGY CAN'T BE CREATED, WHERE DID IT COME FROM IN THE FIRST PLACE?

We're taught at school that energy can't be created, merely converted from one form to another. But at the birth of the Universe – that is, everything – the energy needed for the Big Bang must have come from somewhere. Many cosmologists think its origin lies in so-called quantum uncertainty, which is known to allow energy to emerge literally from nowhere. What isn't clear, however, is why this cosmic energy persisted long enough to drive the Big Bang. *RM*



HOW DID THE ROMANS DO ARITHMETIC WITH THEIR NUMERALS?

Despite our extensive knowledge of the Romans, little is known about how they performed even basic arithmetic using their notoriously unwieldy numerals, where a two-digit number such as 78 becomes the seven-letter horror LXXVIII. Clearly, Roman labourers wanting to work out, say, the area of a floor measuring 78 by 37 paces would take ages to establish it's MMDCCCLXXXVI square paces.

Or would they? Research by cognitive scientists has shown that despite appearances, calculations with Roman numerals can be broken down into steps needing relatively few intermediate results to be remembered. With practice and the use of an abacus, such rules might explain how the Romans coped with the sums needed to build and maintain an empire. ***RM***

WHY DOES LIGHT LEAVE THE POSITION WHERE IT IS CREATED?

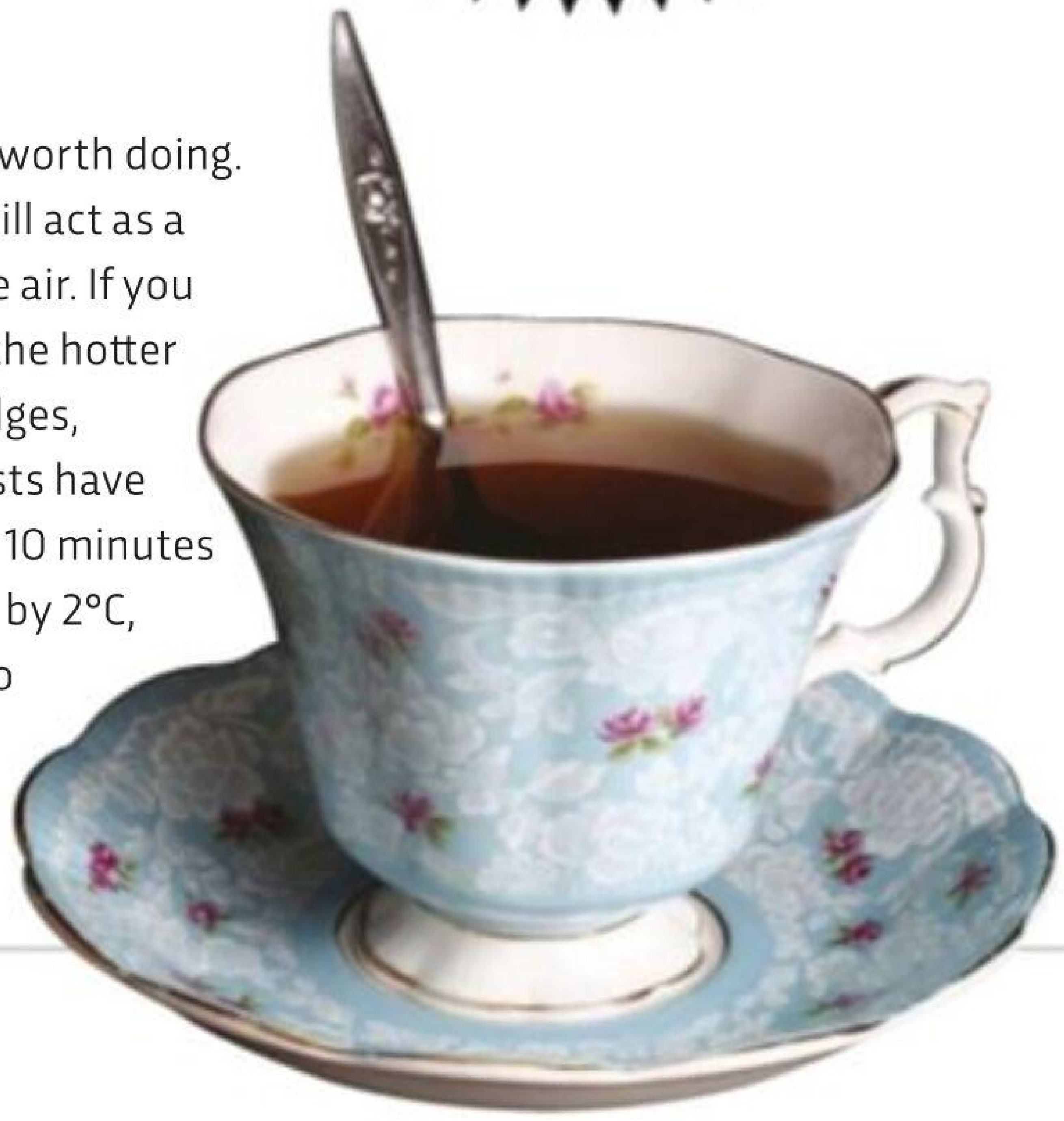
Light is a manifestation of the laws of electromagnetism, which show that whenever sources of electric charge are accelerated, the resulting energy is converted into waves of electromagnetic energy that spread out from the source at the speed of light. In other words, light can't stand still. ***RM***

1,400°C

The temperature that heat shields on NASA's Parker Solar Probe will need to withstand. Although temperatures in the corona reach millions of degrees, there's very little matter there, so the actual heating effect is quite low

DOES A CUP OF TEA COOL QUICKER IF IT'S STIRRED?

Yes, but not enough to make it worth doing. A metal spoon in a cup of tea will act as a radiator, conducting heat to the air. If you stir it as well, you are bringing the hotter liquid from the centre to the edges, where it can cool faster. But tests have shown that stirring a cuppa for 10 minutes will only drop the temperature by 2°C, compared with just leaving it to stand. The fastest way to cool your tea is to add more milk or a splash of cold water. ***LV***



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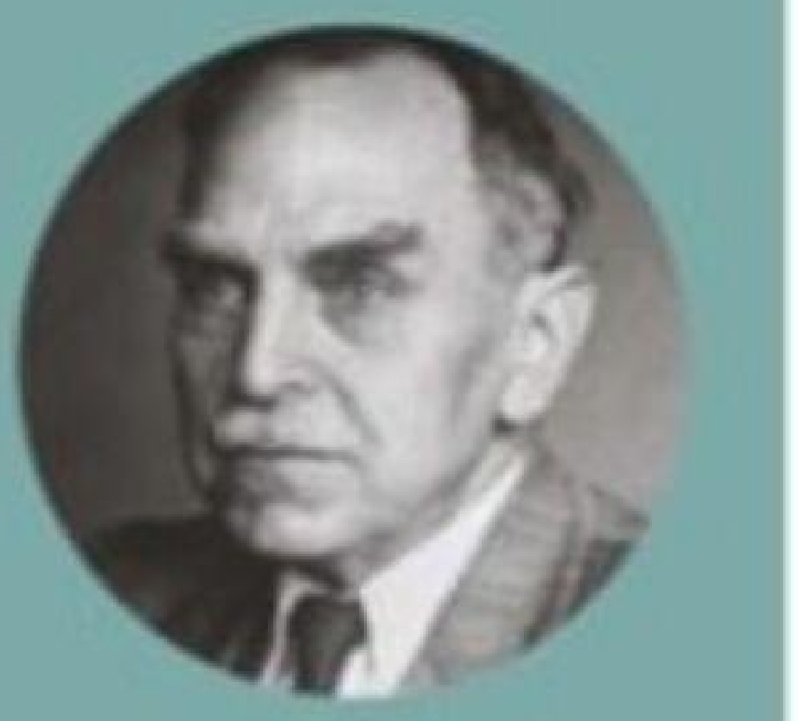
WHO REALLY INVENTED…?

NUCLEAR FISSION



OTTO HAHN

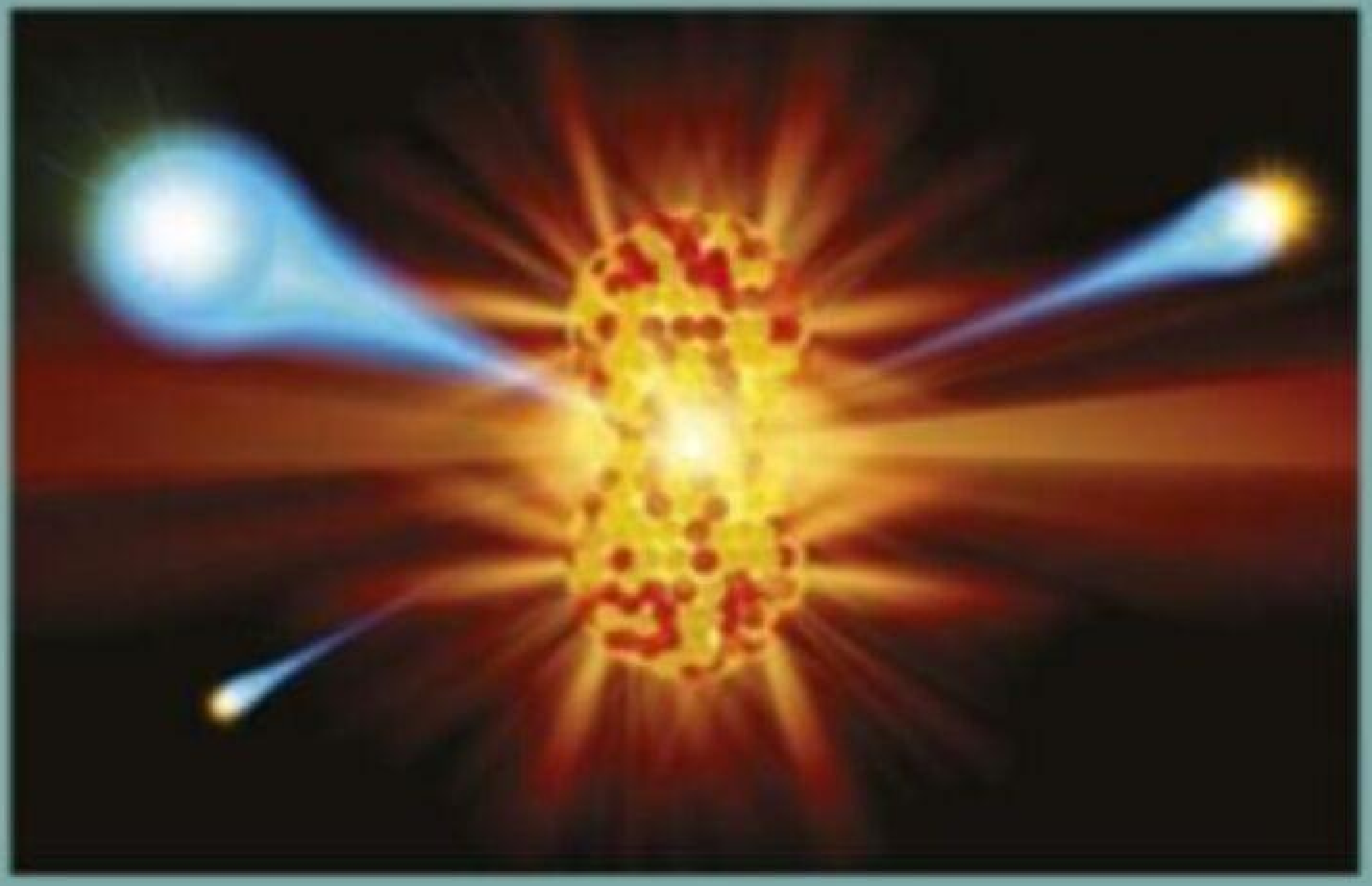
LISE MEITNER

After millennia of exploiting sources of chemical energy, such as wood, the discovery of nuclear fission in the 1930s gave humanity access to something far more potent: energy released by the splitting – 'fission' – of atomic nuclei.

Immediately recognised as the basis of a weapon of mass destruction, and now used to generate around 10 per cent of the world's electricity, nuclear fission has always been controversial. Even its discovery provokes arguments.

What's not in doubt is that nuclear fission was first achieved by a team led by the German chemist Otto Hahn in 1938. Along with his colleague Fritz Strassmann, Hahn found that uranium atoms could be split by bombarding them with neutrons. But baffled that mere subatomic particles could achieve this feat, Hahn contacted Lise Meitner, a former colleague and physicist based in Sweden. Together with fellow physicist Otto Robert Frisch, she showed how fission really worked, and even gave the process its name.

Yet in 1944, the Nobel Committee awarded its chemistry prize solely to Hahn, ignoring the crucial insights of Meitner and Frisch. Historians now believe that, at the very least, Meitner should be regarded as the co-discoverer of nuclear fission and suspect her contribution was overlooked in part because of her gender. *RM*



Nuclear fission involves splitting atoms into smaller parts, and releases a lot of energy

NATIONAL INSTITUTE OF ALLERGY AND INFECTIOUS DISEASES, ROCKVILLE,
MARYLAND

What is this?

The yellow blobs in this image are one of the most dangerous bacteria on the planet, according to the World Health Organisation. Methicillin-resistant *Staphylococcus aureus* (MRSA) bacteria – seen here inside a dead white blood cell – pose a global health threat as they make infections much harder to treat.

MRSA's imperviousness to drugs marks it out as a 'superbug', bacteria that have evolved the ability to withstand antibiotic treatments. The race is on to find new drugs, but in the meantime, health professionals advise that the spread of superbugs can be slowed by using antibiotics only when absolutely necessary.

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WHY DO I HAVE MORE VIVID DREAMS WHEN I SLEEP IN A DIFFERENT BED?

It's well known that our sleep can suffer on the first night in a new environment. Sleep scientists noticed this when they started studying people in sleep labs, dubbing it the 'first-night effect'. One recent study found that the left side of the brain experiences lighter sleep than the right side during the first night. This may be an evolutionary mechanism to keep us alert to potential dangers in new surroundings. We're more likely to remember our dreams better when we wake up a lot, this is probably why your dreams seem more vivid than usual. ***AGr***

WHY DID SLEEP EVOLVE?

Scientists disagree as to why sleep evolved. It seems peculiar that we should spend so much of our lives sleeping when it's at this time that our vigilance is at its lowest and we're at our most vulnerable. It's also a time when we don't typically eat, drink or reproduce. There are a plethora of theories as to why sleep evolved, including the idea that sleep allows us to save or optimise our energy use and keep us alert to danger. Sleep also allows us to clean toxins from our brains and consolidate memories, and it's increasingly clear that it helps in many aspects of our waking lives, from controlling our weight and regulating our emotions, to bolstering our immune systems. *AGr*

GENES & EVOLUTION

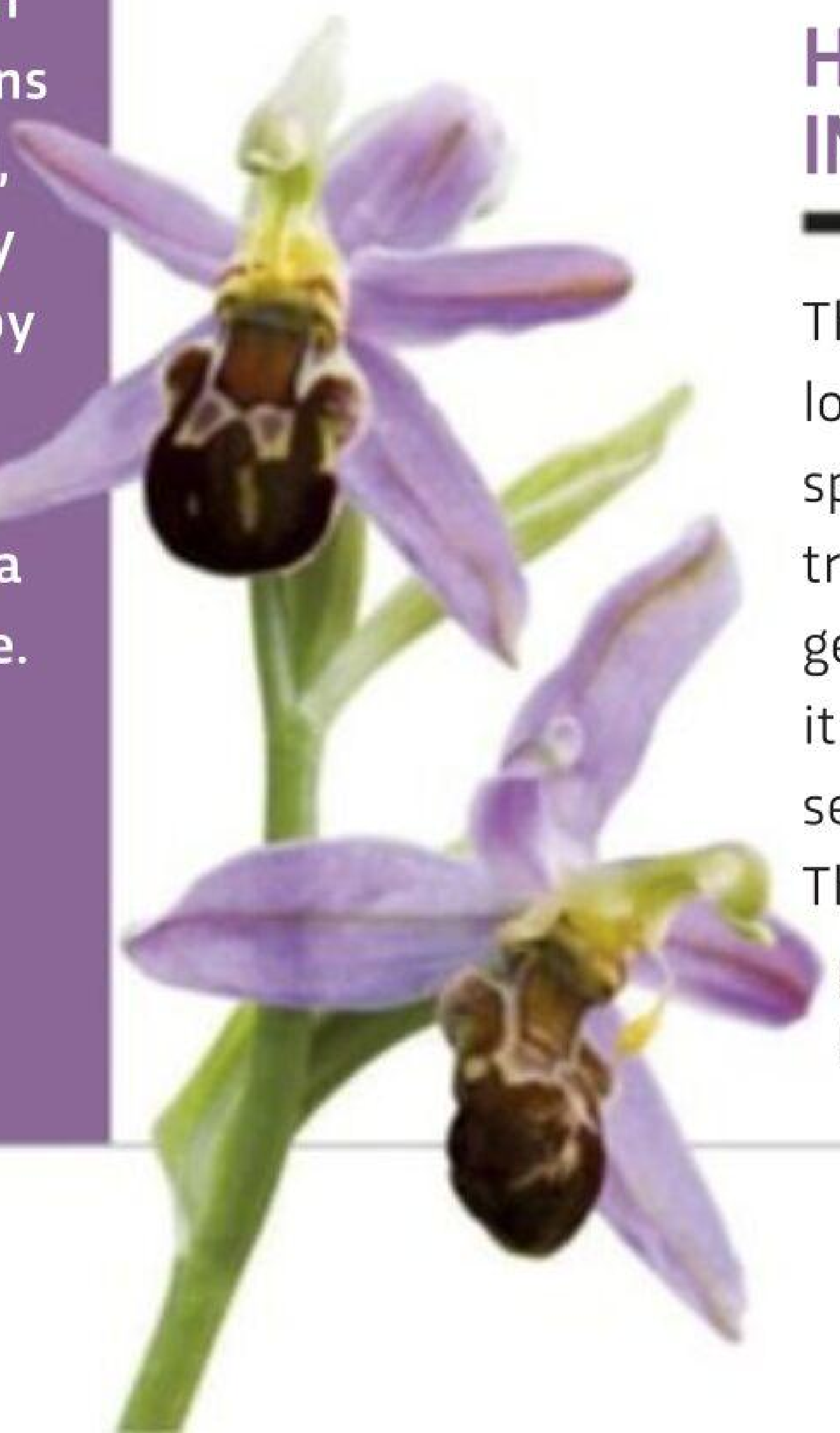
CLONES, SUPERBUGS, ALIEN LIFE, DNA TESTS, SENSES, REPRODUCTION AND NATURAL SELECTION…

WHAT'S THE BIOLOGICAL DIFFERENCE BETWEEN AN IDENTICAL TWIN AND A CLONE?

Identical twins have the same DNA as each other, but different from their parents. A clone, however, only has one parent and has exactly the same DNA as that parent. But even so, a clone isn't a perfect copy. We now know that the way genes are turned on and off is greatly affected by the environment. Twins share the same uterus during development so they are exposed to the same mix of nutrients and hormones. A clone grows in a different uterus and at a different time from the parent animal, so it isn't necessarily identical to the way its parent looked at the same age – even at birth. ***LV***

CAN MEN AND WOMEN EVOLVE SEPARATELY?

They have evolved separately, which is why the sexes are physically different. Evolution has favoured men who have lots of children, so they can easily and frequently produce millions of sperm. Women, on the other hand, need to supply literally all the energy and nutrients required to build a baby from scratch and feed it, so they've evolved a uterus, placenta and milk-producing breasts. But there is a limit to how far the sexes can diverge. Men and women only differ by one chromosome (the Y chromosome) and all the physical and hormonal differences between the sexes have to fit into that one chromosome. ***LV***



HOW HAVE SOME PLANTS EVOLVED TO MIMIC INSECTS WHEN THEY DON'T HAVE VISION?

The bee orchid has flowers that look like the females of a certain species of bee. Male bees are tricked into mating with them, get covered in pollen and spread it to other flowers. Clever as this seems, the bee orchid is oblivious. The ancestor of the bee orchid probably relied on nectar to lure bees, just like other flowers. But then a random mutation made one strain look more inviting to bees than the others. Over time, the flowers that looked most like female bees attracted more pollinators. So they reproduced quicker with less effort. This is a very slow process, but with a few million years and enough bees, you can get a lot done. ***LV***

GETTY IMAGES X4

HAS OUR SENSE OF SMELL EVOLVED BASED ON WHAT IS GOOD AND BAD FOR US?

Yes, we have evolved a higher sensitivity to smells that indicate poison or danger. Rotten fish, for example, smells so bad because it's full of bacteria, and we've evolved to interpret the odour as a warning that eating the fish would likely make us ill. It's true that we become more sensitive to some smells after we learn to associate them with a bad experience. But cadaverine and putrescine, both produced by decaying corpses, smell revolting even if you've never smelled a dead body before. This aversion is shared with lots of animals and evolved at least 420 million years ago. ***LV***

ARE SOME HUMANS MORE EVOLVED THAN OTHERS?

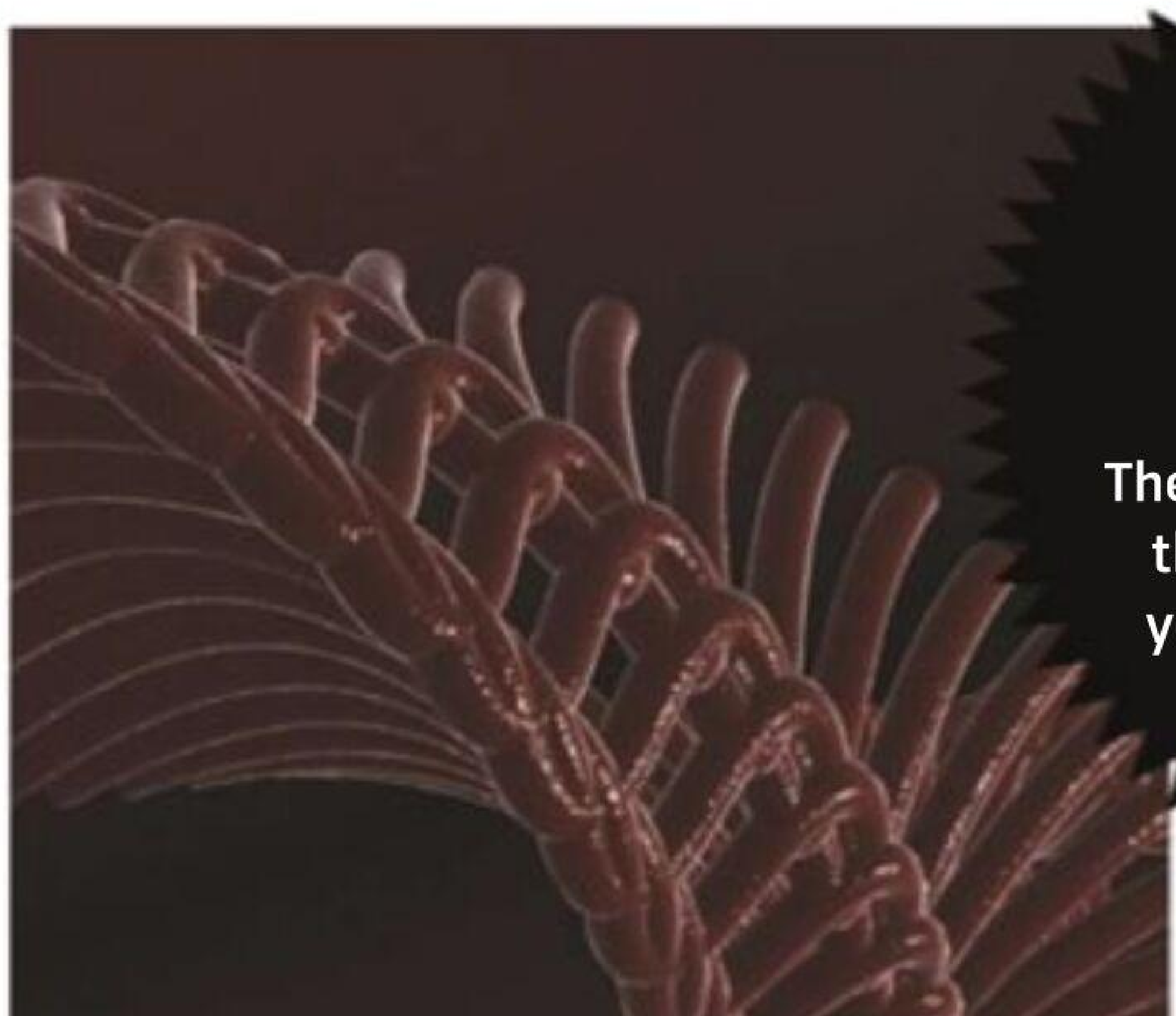
Evolution is a process, not a property. There are people with genes that give them an advantage in certain environments – for example, some people are more resistant to tuberculosis. In a densely populated city with poor living conditions, that person would be better adapted and more likely to pass that gene on. But that's not the same as being 'more evolved'. And if vaccination programs eradicate the disease, then the genetic advantage would disappear.

It's a common mistake to look at animals that have not changed much over millions of years and conclude that they are less evolved. In fact, evolution has affected them just as much as every other species. It's just that natural selection has favoured them sticking to the same design, instead of trying something new. ***LV***

WITH THE RISE OF SUPERBUGS, ARE WE ABOUT TO FIND OUT WHAT IT WOULD HAVE BEEN LIKE TO LIVE IN A WORLD WITHOUT ANTIBIOTICS?

Antibiotic-resistant bacteria, or 'superbugs', are certainly a serious problem. It takes 15 years for a new antibiotic to be developed and tested, but just 10 years of widespread use before bacteria resistant to that drug become common. No new classes of antibiotics have been found since 1984, and drug companies are less interested in looking for new ones because treatments for cancer and heart disease are more lucrative.

But things will never get as bad as they were before the world had antibiotics. Better hygiene and sanitation has vastly reduced the incidence of infectious diseases and helped to contain the spread of antibiotic-resistant strains. In Europe, 400,000 people a year are infected with



WOULD ALIEN LIFE NEED TO HAVE DNA?

The role of DNA is to provide instructions that allow amino acids (the building blocks of proteins needed for the processes of life) to be assembled correctly. DNA also allows those same instructions to be passed down the generations. But DNA isn't unique in this ability, as the related molecule RNA can perform similar functions. It's also possible that alien life exploits radically different ways of achieving similar ends. ***RM***

GETTY IMAGES X6, ALAMY

superbugs, but only 25,000 (six per cent) of these cases are fatal. This many deaths still sounds like a lot, but it's tiny compared to the number that died before we had antibiotics, when half of all deaths were caused by pneumonia, flu, tuberculosis, gastrointestinal infection and diphtheria.

The superbug problem is serious and getting worse, but antibiotics still save a huge number of lives. In the future, we may need to move away from antibiotics altogether and use bacteria-killing viruses known as 'phages' to target the superbugs. ***LV***

Phages, seen here attacking a bacterium, are types of virus that could be used to target superbugs

49

The minimum number of genes that contribute to whether your earlobes are 'attached' or 'hanging free'

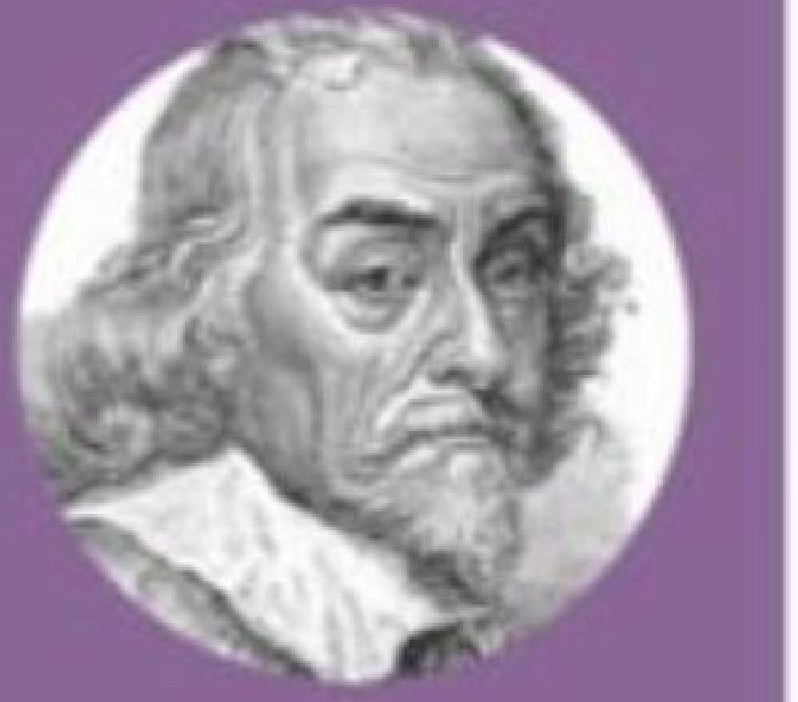
CAN A DNA TEST DIFFERENTIATE BETWEEN A PERSON'S FATHER AND BROTHER?

Yes. You inherit exactly half of your father's genes, so checking 16 genetic markers on both of you is enough for whoever's doing the testing to be 99.99 per cent confident that someone is your father.

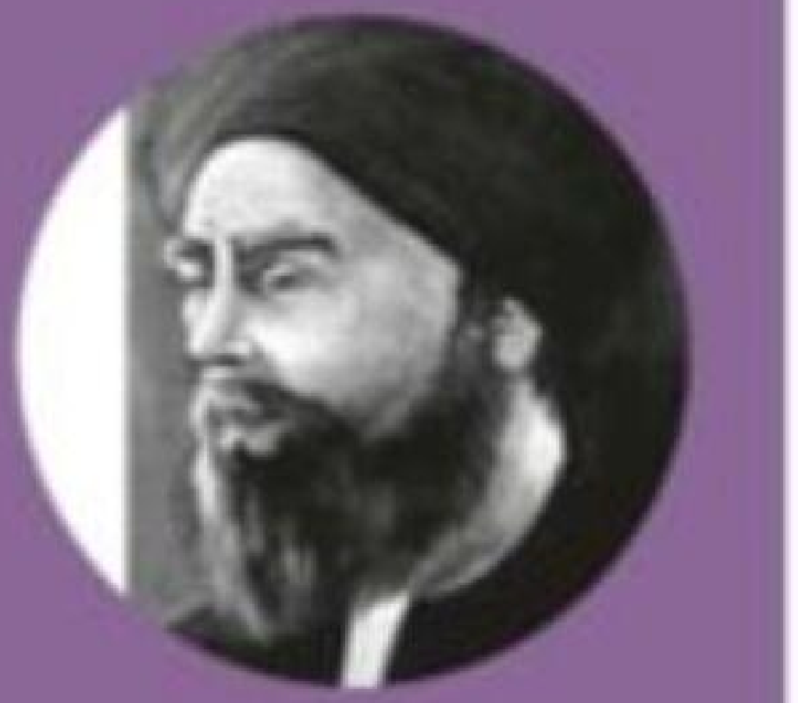
Brothers also share half their genes with their other siblings, but only on average – the exact level of relatedness varies. By comparing lots more genetic markers, a DNA test can show that two siblings are very closely related but cannot be father and son (or father and daughter) because the genetic relatedness isn't exactly hitting the 50 per cent mark. ***LV***

WHO REALLY DISCOVERED…?

HOW BLOOD CIRCULATES



WILLIAM HARVEY

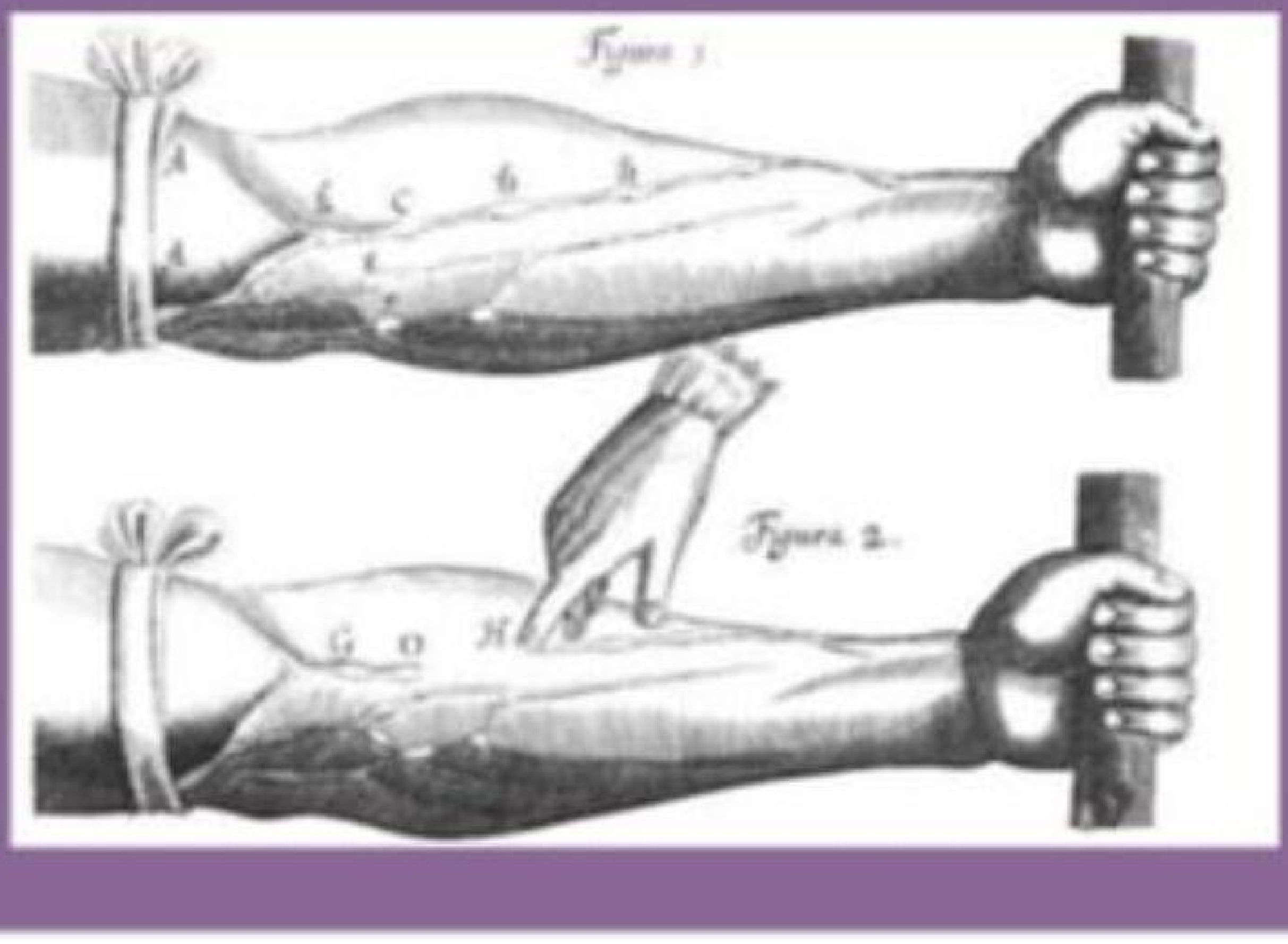


IBN AL-NAFIS

In 1628, the English physician William Harvey created a sensation by publishing a radical new view of how the body uses blood. Until then, doctors had relied on the 1,300-year-old teachings of Galen, a Greek physician, who claimed that blood was created by the liver and then consumed by living tissue. Harvey argued that the amount of blood is fixed, and circulates round the body, being refreshed by passing through the lungs and other organs.

Harvey's revolutionary view implied that blood supply was limited – casting doubt over widely used practices such as 'blood-letting'. After sometimes bitter criticism, Harvey's claims were confirmed and he is now regarded as one of the founders of modern medicine.

But historians have since found that Harvey's revolutionary ideas about the circulation of the blood had already been discovered over 400 years earlier. The 13th-Century Arab physician Ibn al-Nafis showed that the construction of the heart contradicted Galen's claims, and argued that there must be tiny blood vessels allowing blood to circulate. Now called capillaries, their existence was confirmed only in the 17th century. Unfortunately for al-Nafis, his pioneering work remained unknown in Western Europe until the early 20th Century. ***RM***



REDDING, CALIFORNIA

What is this?

This is what was left after the Carr Fire tore through California's Shasta and Trinity counties during the summer of 2018. The fire destroyed over 1,000 homes and killed eight people. It began on 23 July when sparks from a car's wheel rim scrapping along the road surface, due to a flat tyre, ignited dry scrub at the roadside. The resulting blaze couldn't be contained until 30 August.

The 2018 Californian wildfire season was the deadliest and most destructive on record. Experts have warned that climate change could be to blame, with increasing temperatures and dryness leading to fires that burn for longer and with greater intensity.

JUSTIN SULLIVAN/GETTY IMAGES

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IF ALL RADIOACTIVE ELEMENTS DECAY, WHY ARE THERE STILL RADIOACTIVE ELEMENTS ON EARTH AFTER BILLIONS OF YEARS?

Every time a volcano erupts, it's a reminder we live on a seething cauldron of natural radioactive elements. The principal source of geothermal heat is the radioactive decay of isotopes of uranium, thorium and potassium, all of which have been present in the Earth since its formation around 4.5 billion years ago. The reason they're still so potent is that their atoms are disintegrating at a slow rate. This is measured by their so-called half-life: the time needed for their activity to fall by 50 per cent. All three of the main sources of radioactivity in the Earth – U-238, Th-232 and K-40 – have half-lives similar to the age of our planet, and so are still going strong. ***RM***

Heat generated by the decay of radioactive elements within the Earth's crust and mantle helps power a range of geologic processes, including volcanic eruptions

PLANET EARTH

EARTHQUAKES, HURRICANES, OCEANS, CLIMATE CHANGE, CONTINENTAL DRIFT, RECYCLING, TIDES AND WEATHER...

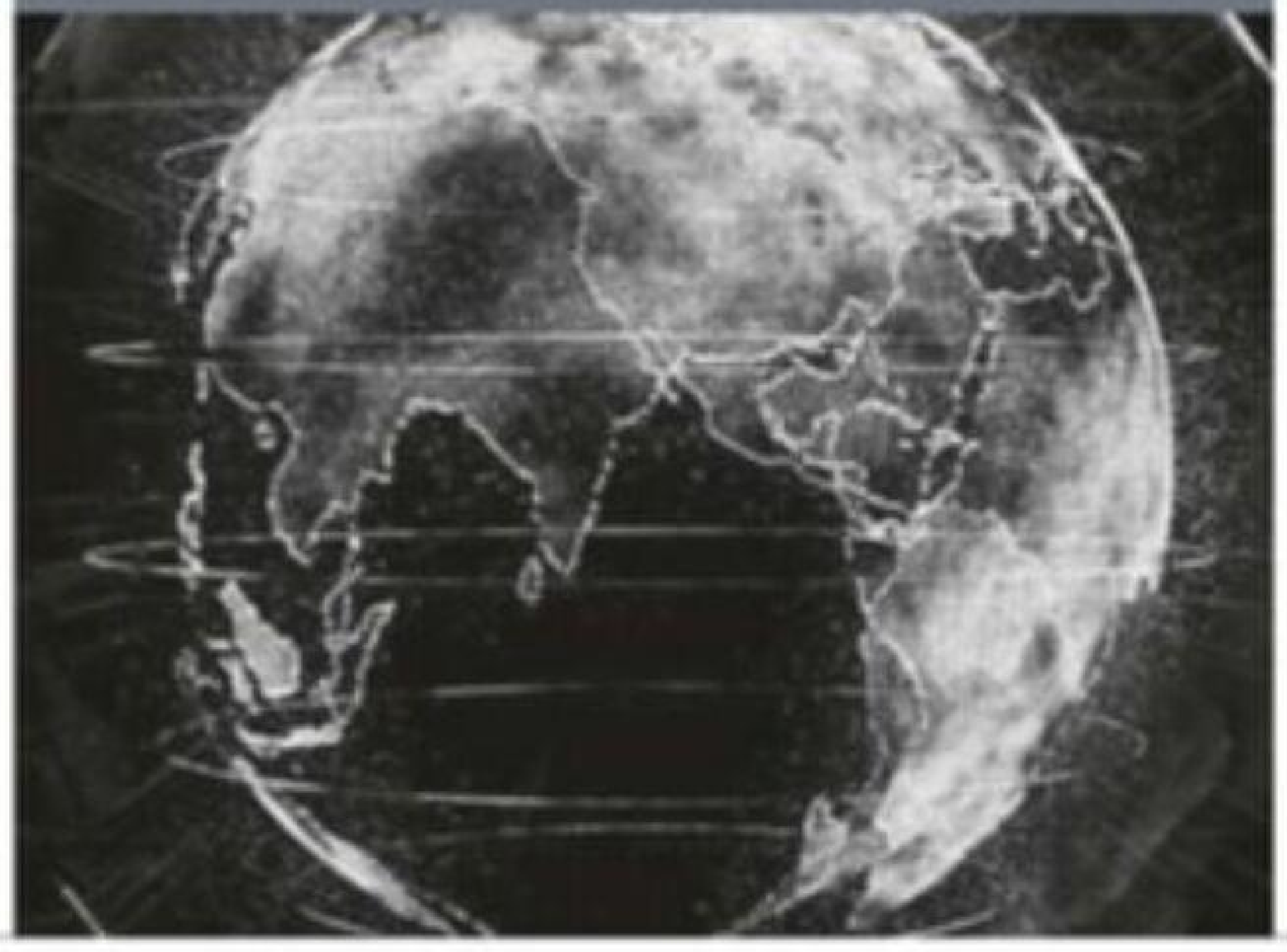
WILL EUROPE GET MORE HURRICANES IN THE FUTURE?

Hurricanes form over warm ocean waters, making them relatively uncommon in Europe. Hurricanes born in tropical Atlantic waters are occasionally diverted northwest by the jet stream, but they gradually peter out as they hit colder waters. By the time they've swung around towards Europe they may no longer technically be classified as a hurricane, but can still cause heavy rain and high winds, as seen with ex-hurricane Ophelia in October 2017. As our climate changes, warmer waters in the North Atlantic could result in hurricanes retaining their intensity over greater distances, increasing the frequency with which such 'super storms' occur in western Europe. ***AFC***

GETTY IMAGES X3

WHY DOES PLANET EARTH SPIN?

The Solar System formed almost five billion years ago from a turbulent cloud of gas and dust. The motions of the atoms and molecules in that cloud were extremely unlikely to average out to be exactly zero – there would have been a tendency for them to move, or rotate, in a certain direction. As the cloud collapsed under gravity, the conservation of angular momentum ensured that the cloud's initial rotation was magnified, eventually flattening it out into a disc. The Earth formed within that disc and spins because it inherited its angular momentum from its 'parent' cloud. ***AGu***

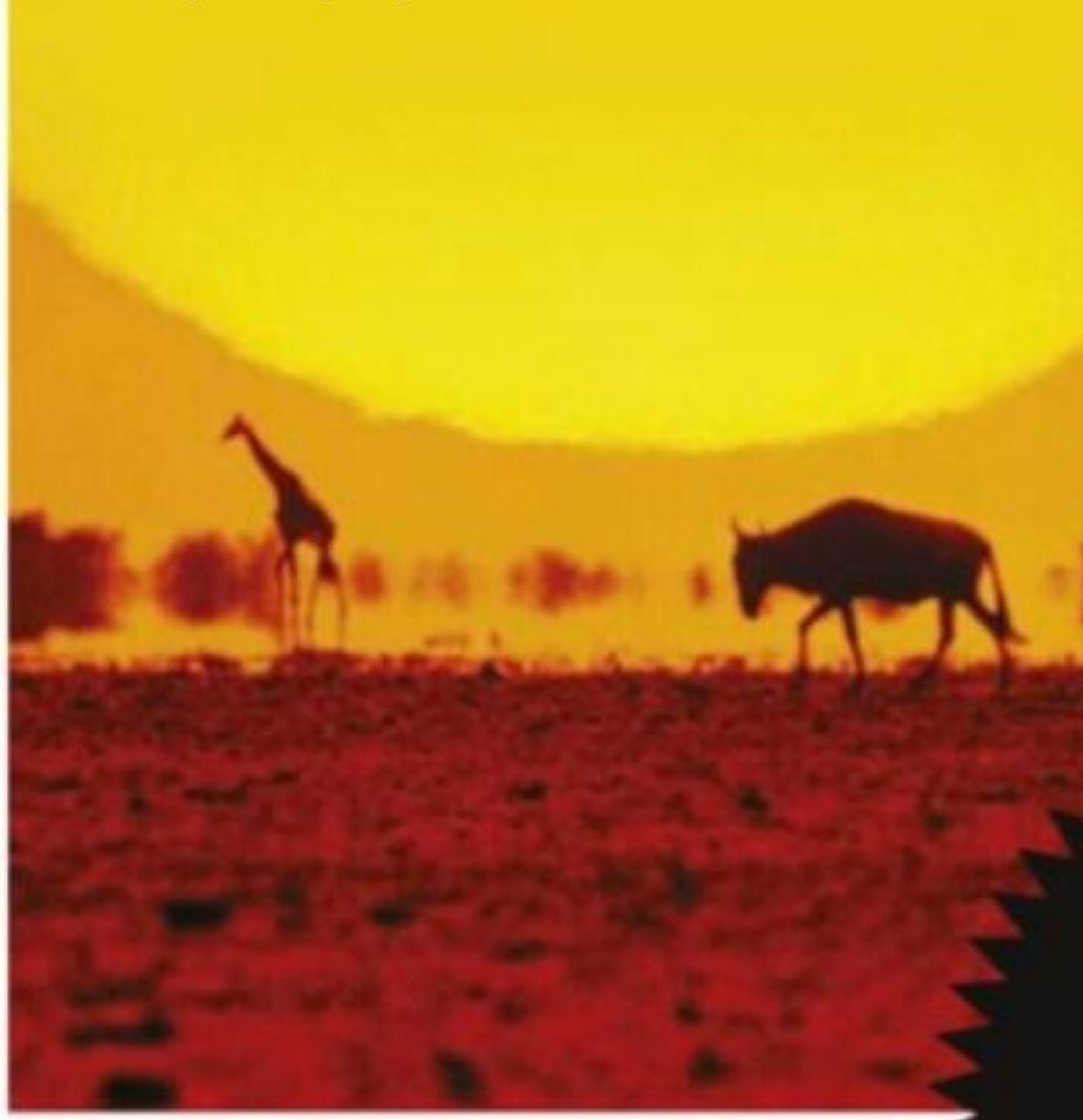


WHAT COLOUR IS WATER?

We usually think of water as being a colourless liquid, but that's not the case. When white light is shone through a long column of the stuff, the liquid appears faintly bluish. That's because the water mops up the longer, redder wavelengths of light, leaving the bluer wavelengths unscathed. As with so many of its properties, however, water does this in a bizarre way, with the light energy being absorbed by its V-shaped H_2O molecules, which start to vibrate as a result. ***RM***

WHY IS AIR INVISIBLE?

Air is made up mostly of nitrogen and oxygen molecules that are spread too thinly to affect light noticeably by, say, altering its colour or intensity. Even so, air's presence is revealed in hot weather through the shimmering effect called 'heat haze'. This is the result of the heat causing fluctuations in the density of the air, which in turn affects its optical properties. ***RM***



HOW DO OCEAN TIDES CREATE MAGNETIC FIELDS?

We're taught in school that we can create electric current by moving electrical conductors through magnetic fields. Known as Faraday's law of induction, it's the idea behind electricity generation in power stations. But shortly after discovering the effect in 1831, Michael Faraday wondered if it might lead to a natural source of electricity. To find out, he tried to detect the current produced by the electrically conducting river water flowing through the Earth's magnetic field under Waterloo Bridge. The experiment, conducted in January 1832, was a failure, but Faraday remained convinced the currents did exist – if only very weakly. More recently, in 2018, a trio of European Space Agency satellites called Swarm were able to detect electric currents generated in the world's oceans as they are dragged through the Earth's magnetic field by the gravitational pull of the Moon. These currents are able to induce their own feeble magnetic fields – around 20,000 times weaker than the Earth's magnetic field. Mapping the oceans' magnetic signature required state-of-the-art equipment unimaginable in Faraday's time. But as well as vindicating the Victorian genius's claim, the research is expected to provide a whole new way to monitor the movements of the oceans. ***RM***

600

The length, in metres, of a floating barrier launched into the Pacific by Ocean Cleanup. The barrier has been designed to collect five tonnes of debris a month. It broke apart on its first deployment but a reinforced model was put to sea in June 2019

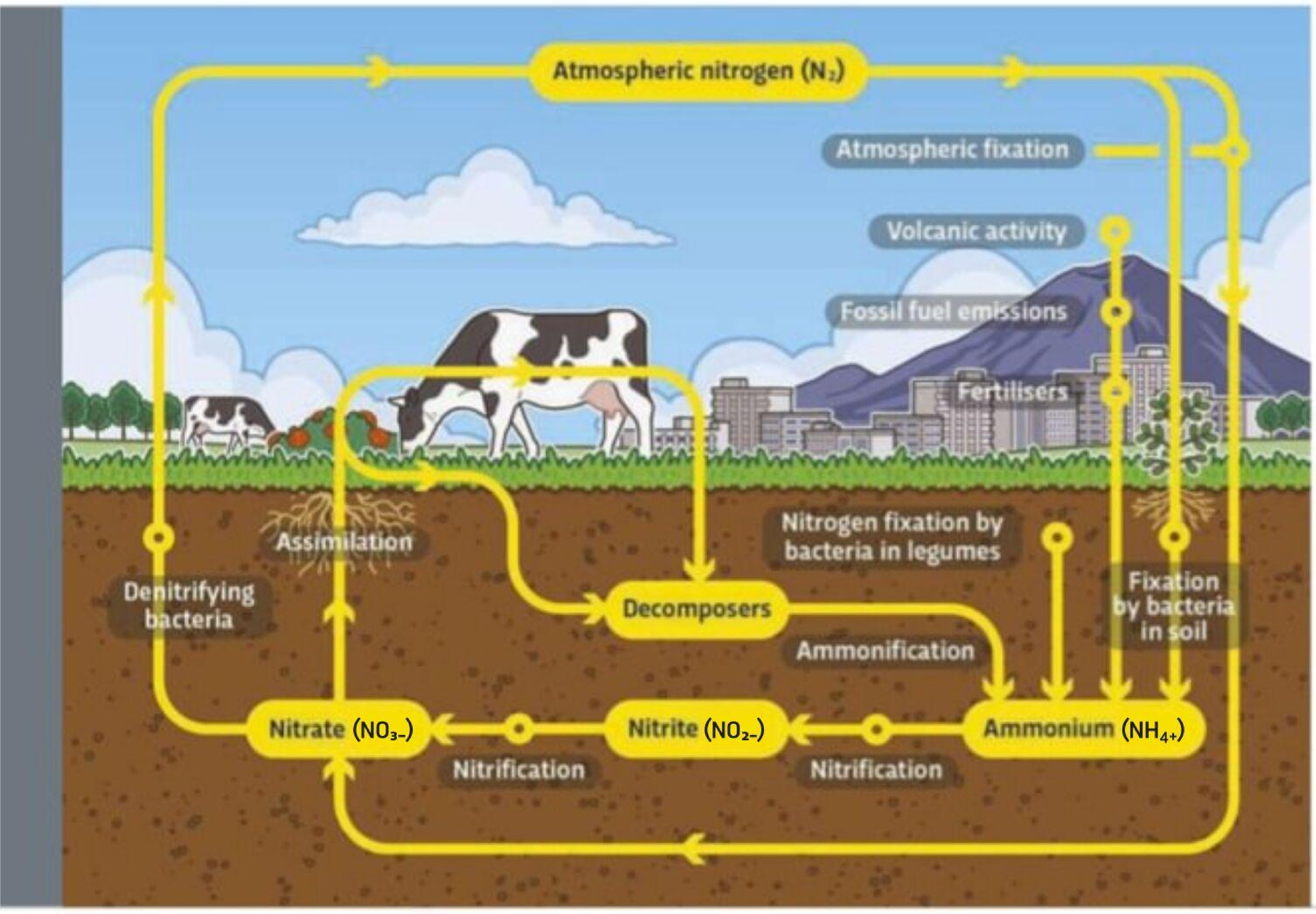
IS THERE ANY REASON WHY PLASTIC BOTTLES CANNOT BE REUSED IN THE WAY GLASS ONES WERE IN THE PAST?

Existing plastic bottles are designed for single use and aren't sturdy enough to withstand the wear and tear associated with collection, cleaning, refilling and reuse on a commercial scale. Reusable bottles need to be sterilised, which involves washing with very hot water and possibly chemical solutions to kill any bacteria. But while glass is resistant to high temperatures and to many corrosive chemicals, most plastics are liable to melt, deform or sustain damage from these cleaning methods. Nonetheless, it might be possible to produce a reusable plastic bottle, but to the best of our knowledge no company has done this yet. ***AFC***

WHERE DOES THE NITROGEN IN THE AIR COME FROM?

Nitrogen makes up 78 per cent of the air we breathe and it's thought that most of it was trapped in the chunks of rock that coalesced to form Earth. Their nitrogen content has been seeping out of cracks in the planet's crust ever since. Nitrogen is only useful to living organisms after it has been 'fixed' into compounds such as ammonia or oxides of nitrogen. Nitrogen fixation is carried out by bacteria, algae and human activity, and once organisms have benefited from it, some of the nitrogen compounds break down and return to the atmosphere as nitrogen gas. Along with top-ups from volcanic eruptions, the 'nitrogen cycle' has kept the level pretty constant for at least 100 million years. ***RM***

GETTY IMAGES X4, RAJA LOCKEY


Atmospheric nitrogen (N_2)
Atmospheric fixation
Volcanic activity
Fossil fuel emissions
Fertilisers
Assimilation
Denitrifying bacteria
Nitrogen fixation by bacteria in legumes
Decomposers
Fixation by bacteria in soil
Ammonification
Nitrate (NO_{3-})
Nitrite (NO_{2-})
Ammonium (NH_{4+})
Nitrification
Nitrification

IS IT BETTER TO WALK OR RUN IN THE RAIN?

It's a question many of us ask when caught in a downpour: is it better to run and get to shelter quicker, or does running mean we encounter more raindrops and get wetter? The amount of rain striking the top of your head each second depends only on how hard it's raining. So, although running faster won't change the rate at which you get wet, it will get you to shelter quicker, minimising your exposure to the rain and keeping you drier. Meanwhile, as you head for shelter, the front of your body also cuts through rain and gets wet. But the total amount of rain you travel through depends only on the distance between you and shelter, and has nothing to do with your speed. Things do get more complicated as you add in the effect of wind speed and direction, but as a rule of thumb, the intuitive answer is right: run towards the nearest shelter as fast as possible. ***RM***

WHY DOES THE UK GET EARTHQUAKES WHEN WE'RE A LONG WAY FROM A PLATE BOUNDARY?

In February 2018, parts of southwest England and Wales were rocked by the strongest earthquake in a decade. By global standards, it was pretty weak. It measured just 4.4 on the Richter scale and caused no major damage, yet it still shocked many. After all, the UK is far from the edge of any of the tectonic plates that make up Earth's crust, and where most quakes occur. Propelled by the heat of Earth's interior, the Eurasian plate beneath the UK is moving in a westerly direction by around 10mm per year and is riddled with fault lines. These often slip slightly, triggering tremors detectable only with specialist equipment. Around once a decade, however, there's a bigger shift that results in an earthquake strong enough to make headlines. ***RM***

Damage to a roof in South Yorkshire, following an earthquake in 2008. The quake registered 5.2 on the Richter scale and was felt across much of the country

GETTY IMAGES X3, RAJA LOCKEY, PRESS ASSOCIATION

IF WE WERE ABLE TO DIG TO AUSTRALIA, AT WHAT POINT WOULD YOU STOP DIGGING DOWN AND START DIGGING UP?

To dig from London to Sydney, you would actually need to angle about 15° off the vertical, in a roughly easterly direction, so technically you are never digging straight down. Your tunnel would reach its closest point to Earth's centre after about 6,150km and would slope upwards after that. Assuming, of course, that we ignore all the physical impossibilities inherent in such a project. ***LV***

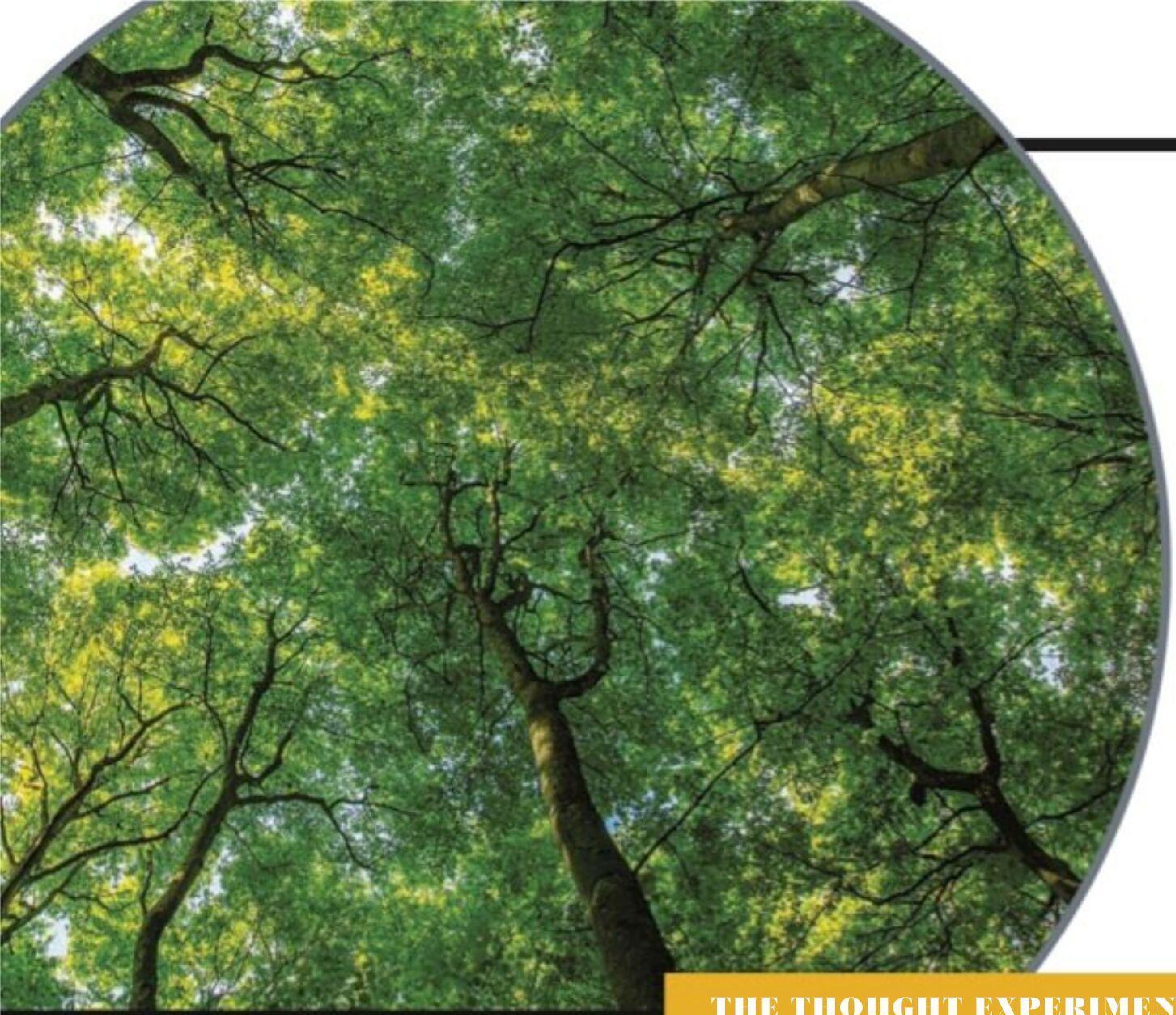
32.5bn

Total carbon emissions in tonnes from Earth in 2017 – the first rise for three years. Research is currently underway to determine 2018's emissions, but the figure is projected to have risen to 37.1bn, an all-time high

COULD THE SEA EVER BECOME TOO SALTY FOR LIFE TO EXIST?

The concentration of salt in the Dead Sea is almost 10 times higher than the average for the rest of the oceans. This is far too salty for fish and plants, but even here there are some bacteria and fungi that can survive. The Dead Sea's high salinity is because the water is evaporating much faster than fresh water flows in. In the open ocean, whatever water evaporates must eventually return. Rivers continually wash more salt in from the land, but the sea has reached equilibrium now, and extra salt just precipitates out of solution onto the ocean floor. *LV*

The Dead Sea is a salt lake with a salinity of 34.2 per cent. It is 9.6 times saltier than the ocean

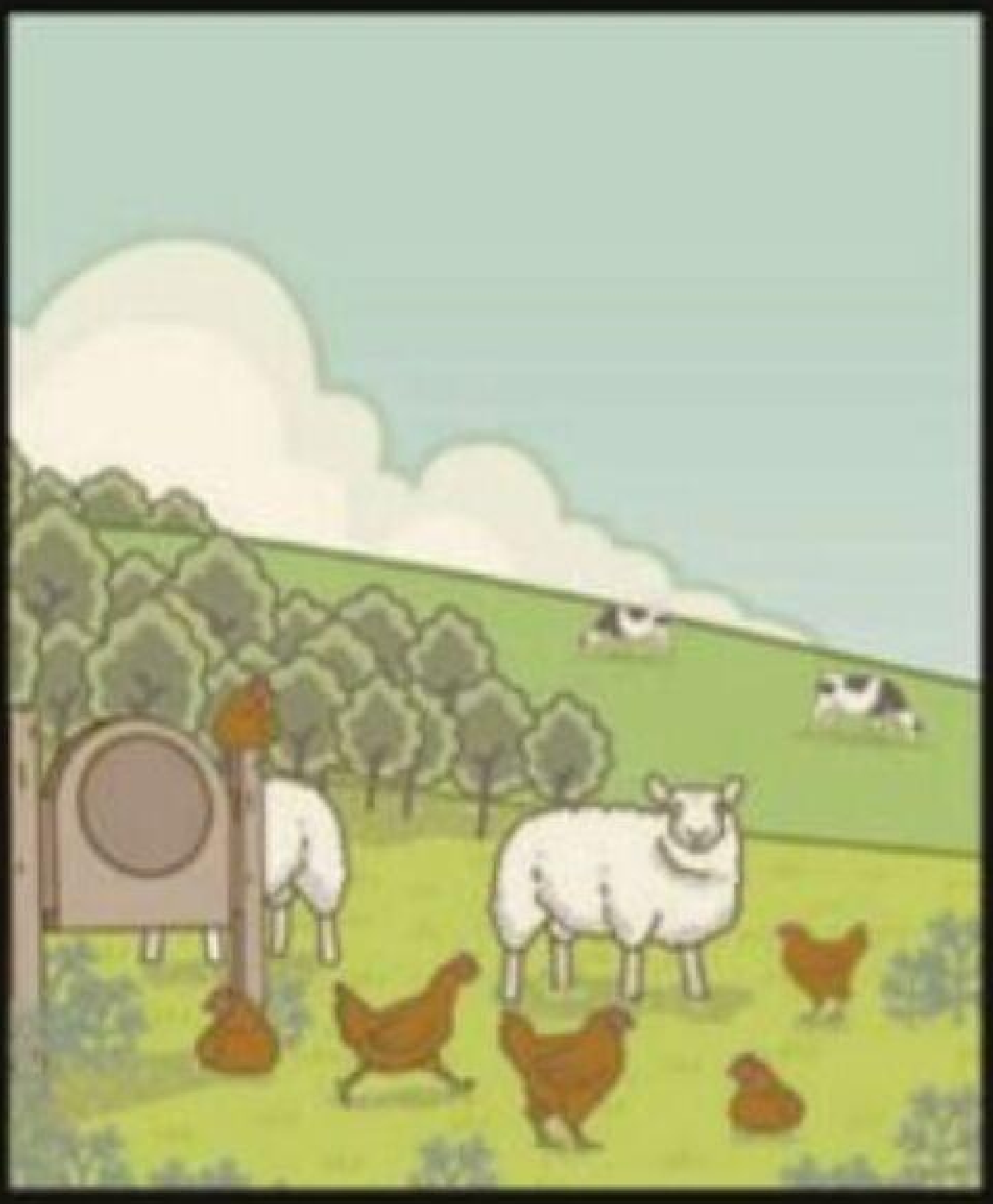


WHEN TREES GROW, WHERE DOES THE MATTER COME FROM?

Trees get their matter from the carbon dioxide in the air, and the water they take in through their roots, with just a small amount of nutrients coming from the soil. During photosynthesis, trees use the Sun's energy to break apart the carbon dioxide (CO_2) and water (H_2O) molecules to form glucose ($C_6H_{12}O_6$) and oxygen (O_2). Some of this glucose is used to respire, while the rest goes into forming cellulose, the primary building block for new branches, stems, leaves and roots. ***AFC***

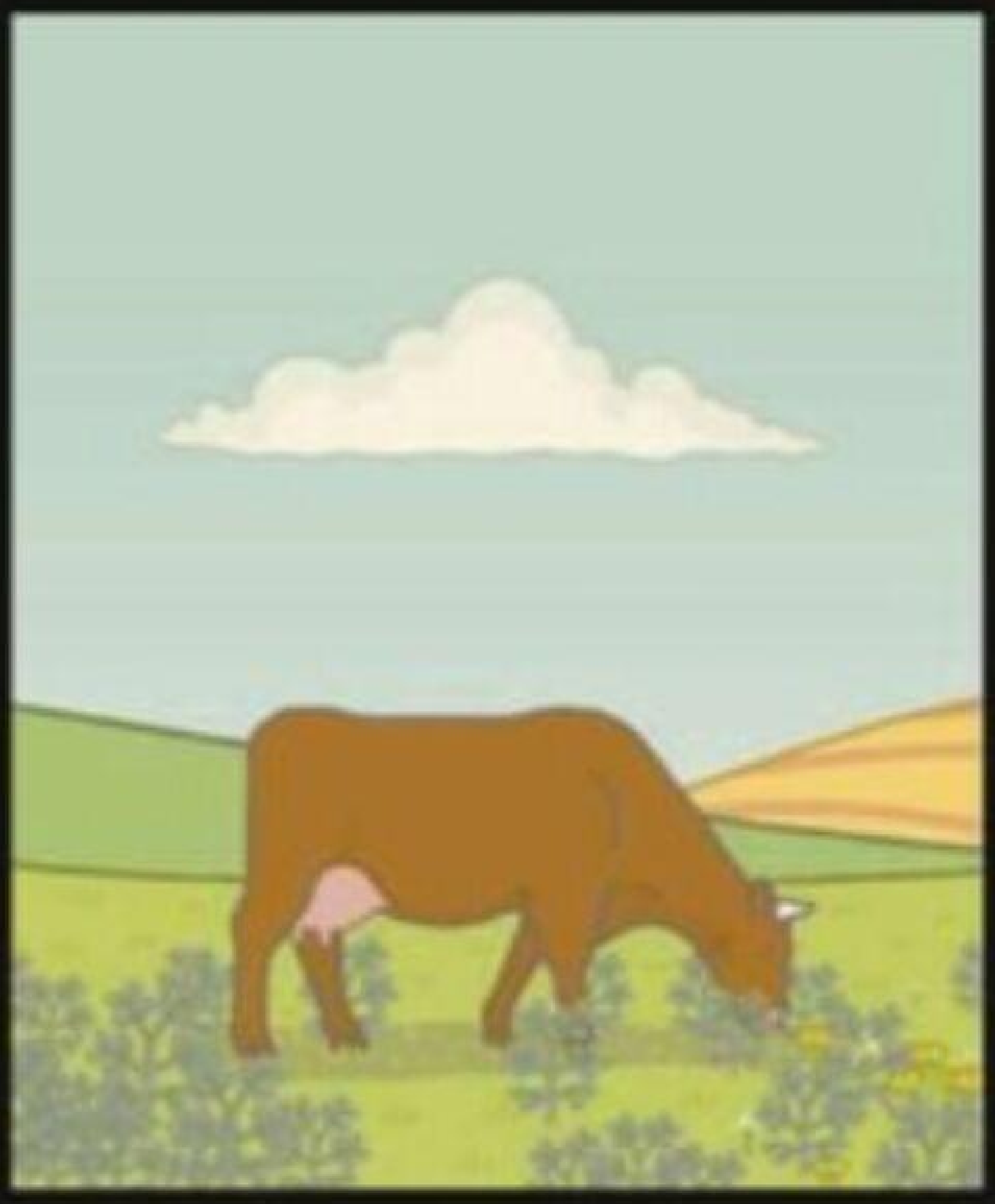
THE THOUGHT EXPERIMENT

WHAT WOULD HAPPEN IF EVERYONE ON THE PLANET SUDDENLY WENT VEGAN?



1. ANIMAL SANCTUARIES

Veganism seeks to exclude all cruelty to animals. Opening the farm gates to the existing stock of 3.5 billion grazing animals and 19 billion chickens wouldn't work. Most would starve to death or be eaten by predators. Instead, farms would need to be turned into sanctuaries for the remaining natural lives of the animals.

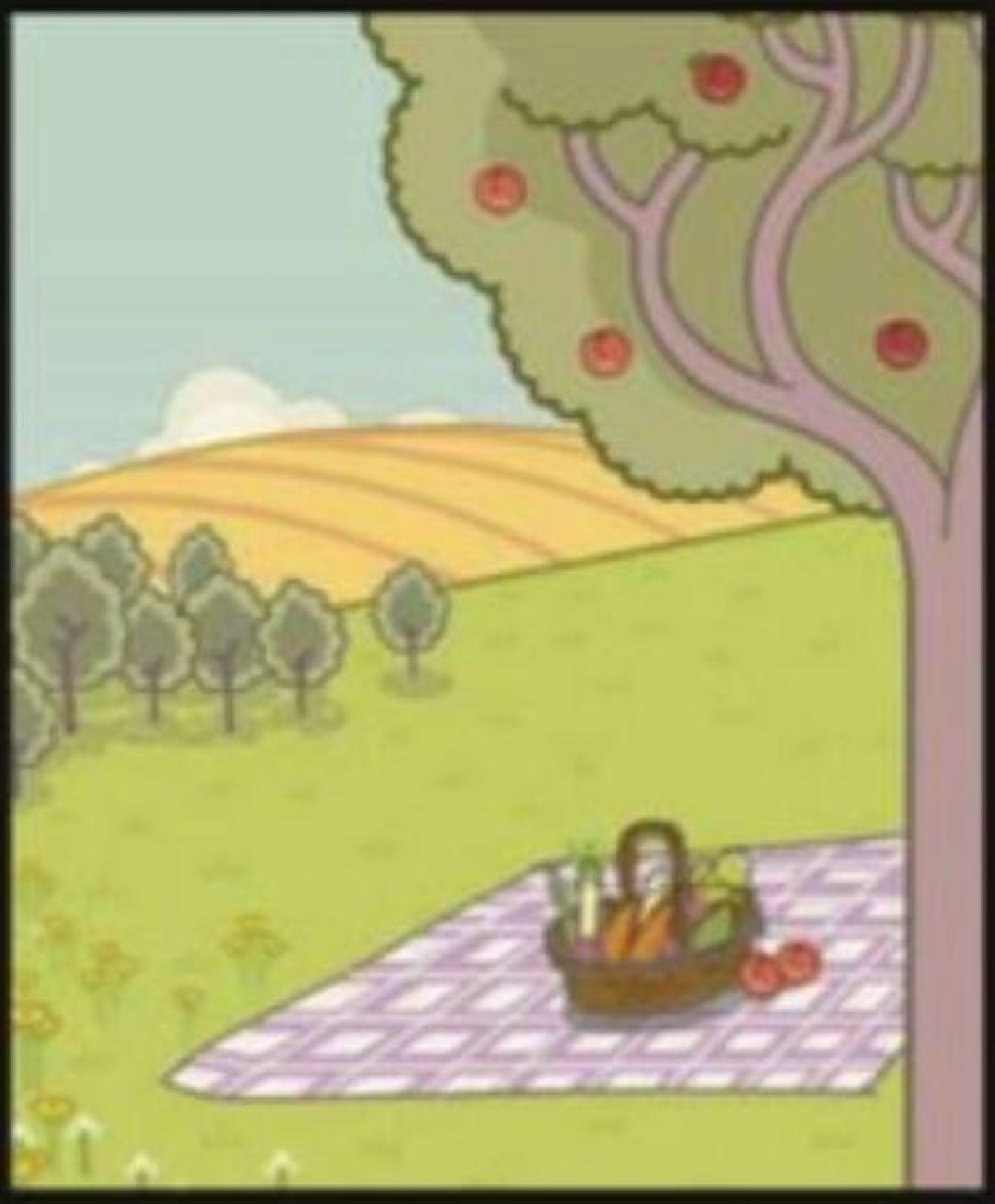


2. EMISSIONS

Food production is responsible for a quarter of all greenhouse gas emissions, mostly from cows burping methane. Methane is such a potent greenhouse gas that a global switch to plant-based diets would cut emissions from food production by 28 per cent – that's the equivalent of India going carbon neutral.

3. LAND USE

Currently, 68 per cent of farmland is used for livestock. Planting a fifth of this with crops would produce the same amount of food as all the animals. This would leave 26 million square kilometres spare – an area 1.5 times the size of Russia – that could be planted with meadow or forest, to improve biodiversity.



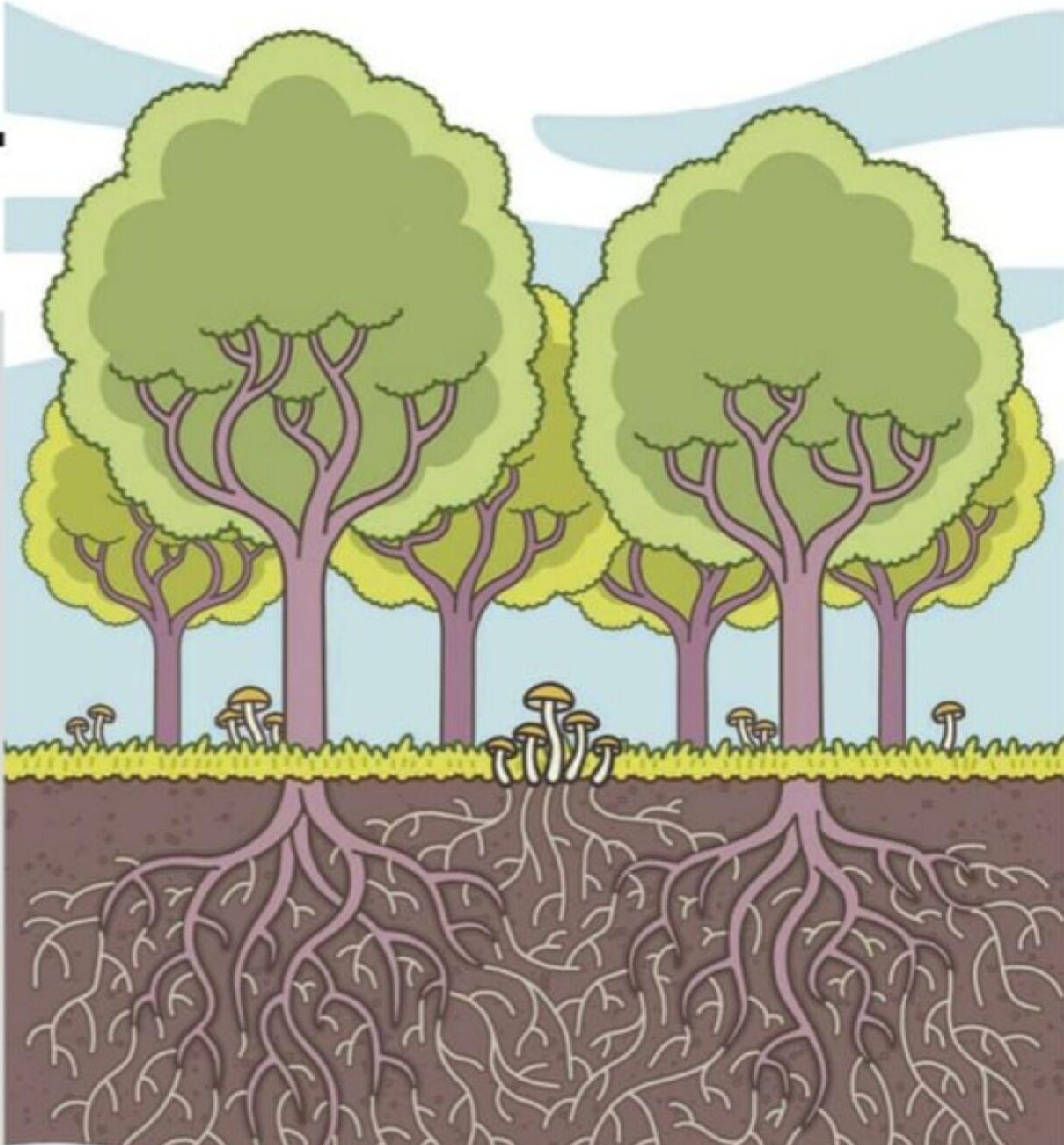
4. HEALTH

If we all gave up meat, around eight million fewer people would die each year, due to lower levels of heart disease, strokes and cancer. But most crops have lower levels of micronutrients per calorie than meat – especially vitamins A, B12 and D, and some fatty acids. Crops would have to be adjusted to avoid malnutrition.

CROWDSCIENCE

CAN PLANTS TALK?

We teamed up with the folks behind BBC World Service's *CrowdScience* to answer your questions on plant life. Tune in to *CrowdScience* every Friday evening on BBC World Service, or catch up online at bbcworldservice.com/crowdscience



DO PLANTS TALK TO EACH OTHER?

Plants may not seem particularly chatty, but there's a silent stream of information passing between them. Beneath the soil, the roots of most plants interact with tiny branching strands of fungi, known as mycorrhiza. It's a two-way deal: fungi provide nutrients from the soil, while the plants provide sugars made in their leaves through photosynthesis. But the fungi don't restrict their interactions to individual plants: they form a network that spans entire forests. Botanists now know that plants can pass nutrients and chemicals through this network, known as the 'wood wide web'. ***RG***

CAN PLANTS COMMUNICATE WITH INSECTS?

We've long known that flowering plants use colour and scent to attract insects, but scientists have recently discovered that flowers also use electricity to communicate with their pollinators. Flowers tend to have a negative electric charge, while bees tend to be positively charged. A 2013 study at the University of Bristol found that a bee's visit will change a flower's electric potential, which may be the flower's way of telling other bees that its nectar reserves have just been snaffled. What's more, some flowers are able to electrically 'fire' pollen at bees as they fly past, without the insects even having to touch the petals. ***RG***

WHAT DO PLANTS TALK ABOUT?

Plants use their fungal network to warn each other about dangers. When a plant is infested with sap-sucking aphids or other insects, a chemical signal is produced that is transmitted through the web. Nearby plants respond by pumping anti-insect toxins into their sap, reducing the chances of an attack. Family is important to plants, too. Mustard seedlings send signals that identify themselves to their siblings, helping them to grow without competing with each other for root space. But there's also a dark side to all this – the phantom orchid, for example, is known to hack the web system to steal carbon from nearby trees. ***RG***

Rory Galloway is the producer of 'Do Plants Talk About Sex?' an episode of *CrowdScience*.

GETTY IMAGES X3, RAJA LOCKEY

Roots provide a plant with nutrients from the soil and enable it to send chemical messages to other plants nearby

DO PLANTS THINK?

Plants don't have a central nervous system, so thought (as we normally define it) isn't possible. But plants can sense their environment, respond to insect attacks and are even capable of limited movement. These reactions are driven by chemical signals – rather than nerve impulses – so it's more like your immune system or unconscious hormonal responses, than conscious or deliberate thought. ***LV***

HOW DO VENUS FLYTRAPS KNOW WHEN TO SHUT?

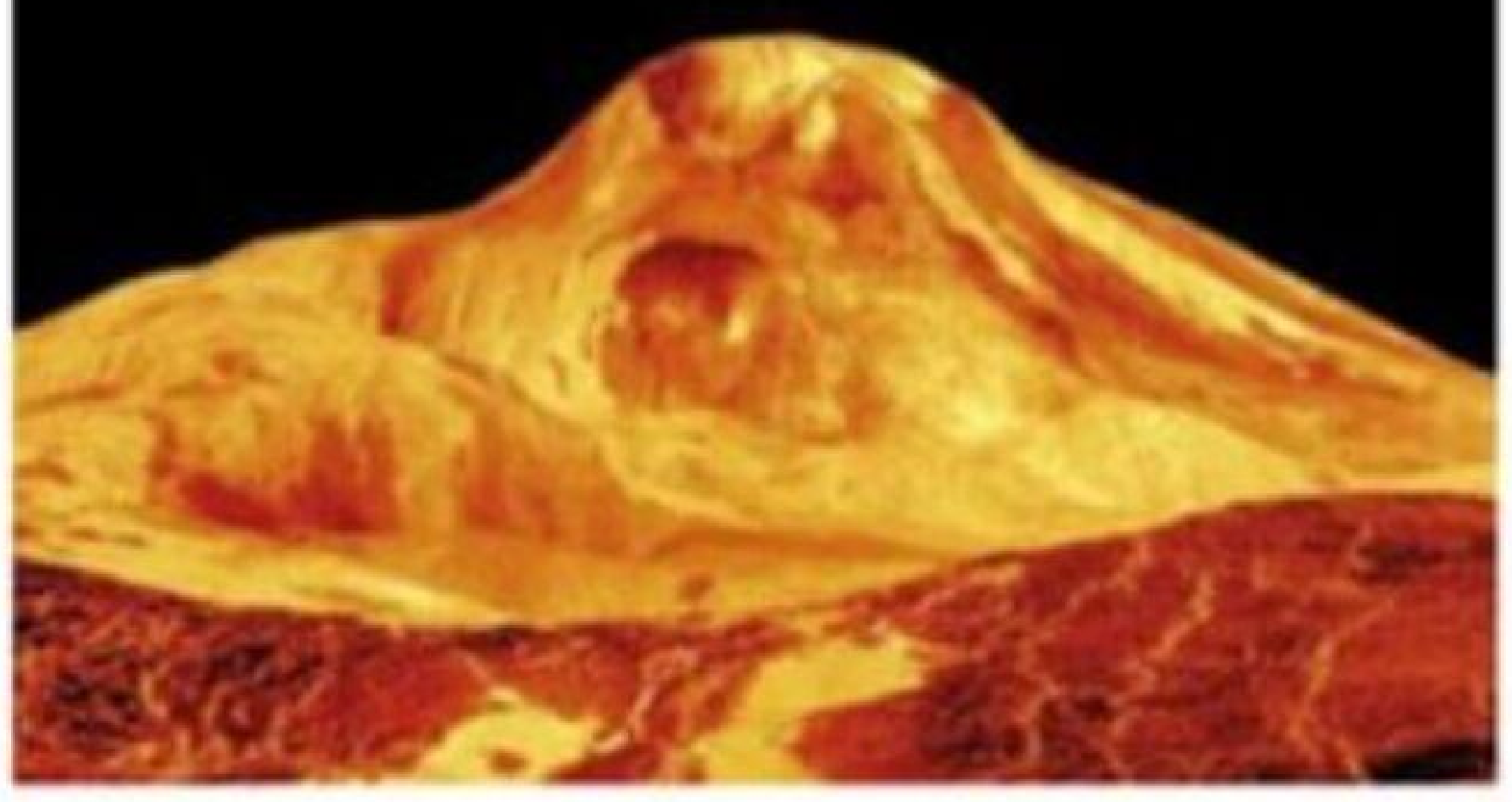
The inside surfaces of the Venus flytrap's two 'lobes' each have three sensitive hairs. Moving these 'trigger hairs' is what springs the trap – but two hairs have to be touched within 20 seconds of each other for this to happen. This has evolved as a safety measure to stop the trap from going off when a raindrop hits it. Initially, the trap only closes loosely, in order to allow tiny insects that aren't worth the trouble of digesting to escape. But anything large enough to touch the trigger hairs another five times will cause the trap to close all the way – eventually forming a watertight seal so that enzymes can be released to digest the insect. ***LV***

HOW DOES OCEAN ACIDIFICATION IMPACT MARINE LIFE?

There'll be many losers among marine life as the oceans absorb humanity's CO_2 and pH falls. An eight-year study involving 250 scientists recently revealed a complex picture of changes rippling through food webs. Organisms with carbonate exoskeletons – like starfish, mussels and sea butterflies – tend to suffer because their shells become unstable. Young animals are especially at risk; cod larvae are twice as likely to die at lower pH. Barnacles and a few other robust animals can adapt but may still suffer from the combined impacts of other threats, like plastic pollution and rising temperatures. ***HS***

COULD CLIMATE CHANGE TURN EARTH INTO VENUS?

Venus's atmosphere is 96 per cent CO_2, driving a powerful greenhouse effect that creates surface temperatures of up to 450°C. Earth's atmosphere, on the other hand, currently contains 0.04 per cent CO_2, with trace amounts of other greenhouse gases. Even if we were to burn all available fossil fuels, the likely impact on our planet's temperature would be a 10°C rise. This may seem modest by Venus's standards, but it would be enough to cause a sea level rise of more than 50 metres. ***AFC***



LARGE CLOUDS CAN WEIGH TONNES. HOW DO THEY STAY UP?

Air is mostly nitrogen (N_2) and oxygen (O_2), with an average density of 1.225kg/m^3. A water vapour molecule is much lighter with just one oxygen atom and two hydrogen atoms (H), so its density (at standard temperature and pressure) is only 0.804kg/m^3. This is why water that evaporates from the sea rises up into the sky in the first place.

At a certain height, the air cools enough for the water vapour to condense into droplets and form visible clouds. The droplets are liquid water and therefore denser than air, but they are tiny, so they have a low terminal velocity and fall very slowly. A typical cloud only has about 0.5g of water per cubic metre in it, and if the droplets are small enough, they will be kept aloft by the thermals in the cloud as warm air rises from below. Once the droplets have fused together and grown large enough, gravity dominates over buoyancy and they fall as rain. *LV*

DOES CONTINENTAL DRIFT AFFECT THE CLIMATE?

Propelled by the circulating heat of Earth's interior, the vast rocky plates forming the crust move barely a few centimetres a year. Yet over time they have had a profound influence on Earth's climate. Today's continents were once part of a huge supercontinent known as Pangaea, which began to break apart around 175 million years ago. At the time, the planet was much warmer than today, but the fragmentation of Pangaea led to massive changes in land distribution, and ocean and atmospheric circulation patterns, triggering radical climate change. Collisions between plates have triggered further change. For example, around 35 million years ago the plate carrying modern-day India started pushing under the Asia plate to create the Himalayas, which affect global wind patterns and drive the monsoon season to this day. ***RM***

GETTY IMAGES X7, ALAMY

WHY ISN'T THE EARTH PERFECTLY SPHERICAL?

Earth's rotation creates an outward force perpendicular to its rotation axis, which, crucially, is proportional to the distance from that axis. Hence, the highest force is felt at the Earth's equator, while the force is zero at the poles. Since the Earth is not perfectly solid throughout, this force results in the Earth being 'squashed' into a slightly flattened sphere. The effect is quite small: the diameter at the poles is about 12,714km and at the equator is about 12,756km; hence the amount of flattening (or 'oblateness') is only about 0.3 per cent. But this equatorial bulge (42km) is about twice the distance from the top of Mount Everest to the deepest part of the ocean. ***AGu***

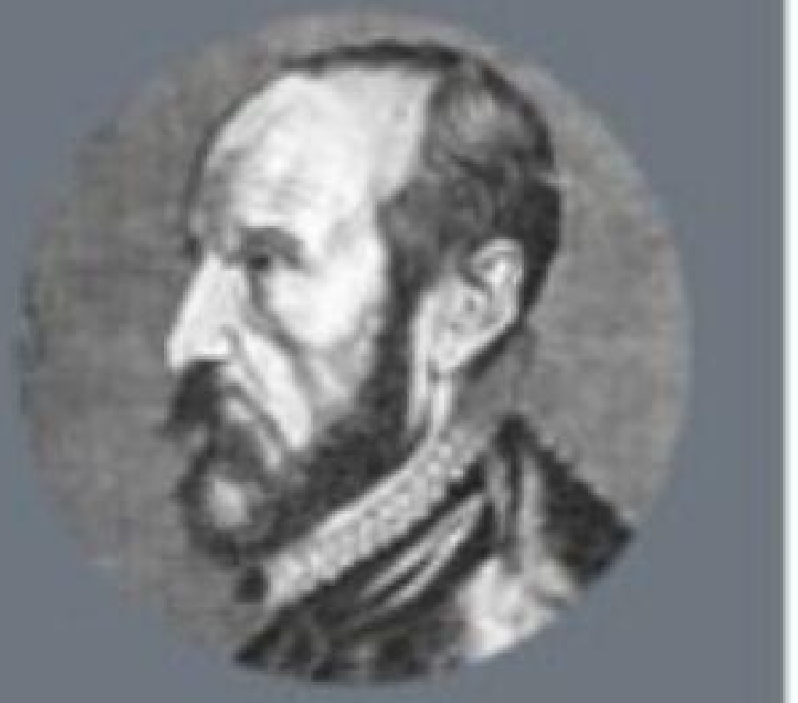
79,000

The mass, in tonnes, of waste floating in the Great Pacific Garbage Patch

WHO REALLY DISCOVERED…?

CONTINENTAL DRIFT

ALFRED WEGENER

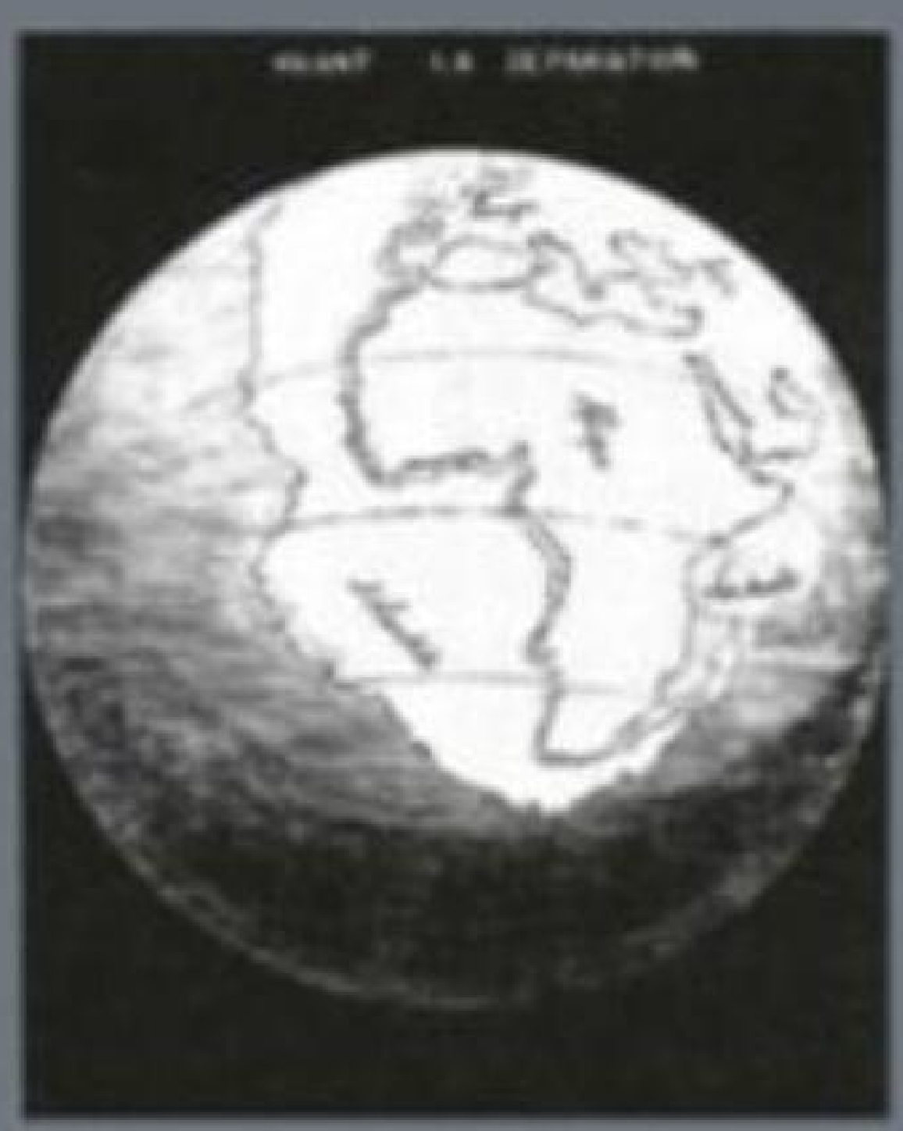


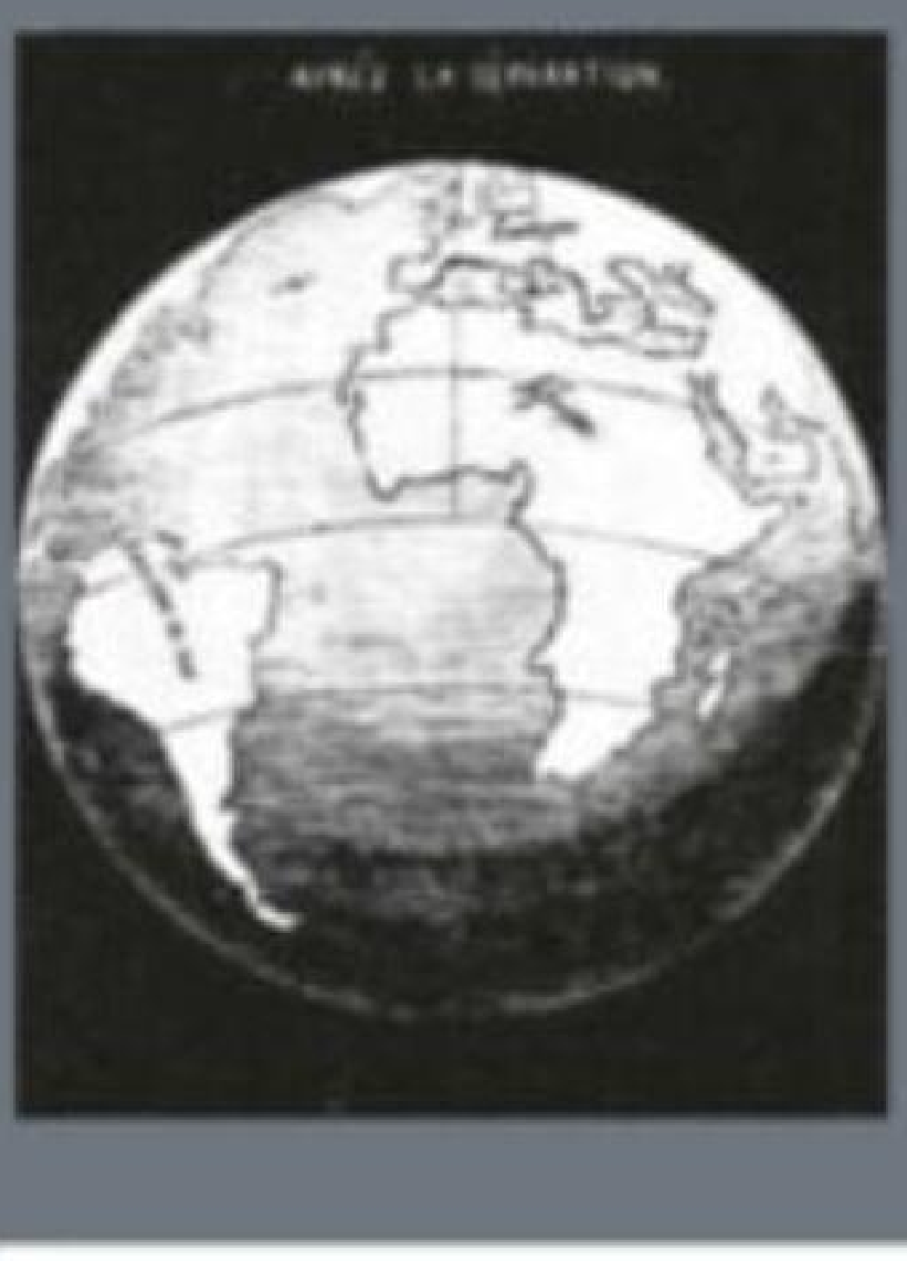
ABRAHAM ORTELIUS

In January 1912, the German meteorologist and explorer Alfred Wegener unveiled an astonishing new vision of Earth's past. According to Wegener, the world we see today is the result of the disintegration of a colossal landmass into separate continents, which have been moving around ever since.

The theory of continental drift provoked outrage, despite the idea having been in circulation for centuries. As long ago as 1596, the Flemish mapmaker Abraham Ortelius had pointed out something that others had doubtless already noticed: that the Americas and Africa seem to fit together as if they were jigsaw pieces (see below). He argued this was no coincidence, and that the Americas had been "torn away from Europe and Africa… by earthquakes and floods". In 1858, the French geographer Antonio Snider-Pellegrini went further, pointing out that fossils of similar plants appeared on both sides of the Atlantic. Presaging Wegener, Snider-Pellegrini argued that there had once been a single landmass that had disintegrated, though he ascribed the cause to the biblical Great Flood.

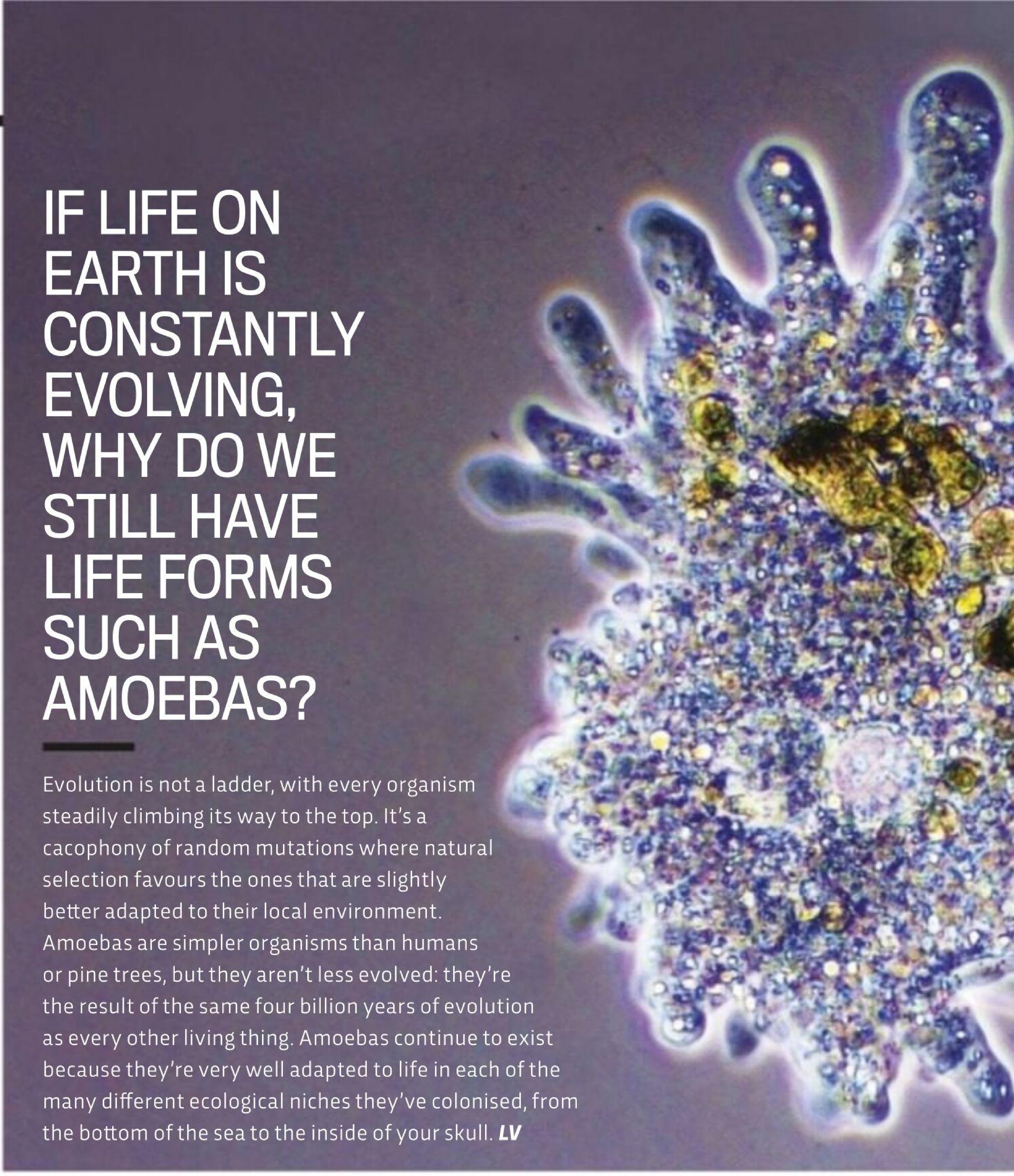
Wegener himself never found a compelling explanation for the driving force of continental drift. But we now know it's down to the roiling motion of vast convective loops of hot rock beneath Earth's shattered crust. ***RM***





WHY DOES RAIN SMELL SO GOOD?

The fresh, earthy smell that we associate with rain, known as 'petrichor', comes from a variety of sources. During dry conditions, certain plants release oils, which then become airborne under the impact of rain. Falling raindrops also stir up the soil, propelling a musky-smelling chemical secreted by bacteria, called geosmin, into the air. Finally, lightning can split molecules in the atmosphere to form ozone (O_3), which has a chlorine-like tang. Interestingly, some scientists speculate that the importance of rain to our survival has led us to evolve to enjoy its smell. ***AFC***



IF LIFE ON EARTH IS CONSTANTLY EVOLVING, WHY DO WE STILL HAVE LIFE FORMS SUCH AS AMOEBAS?

Evolution is not a ladder, with every organism steadily climbing its way to the top. It's a cacophony of random mutations where natural selection favours the ones that are slightly better adapted to their local environment. Amoebas are simpler organisms than humans or pine trees, but they aren't less evolved: they're the result of the same four billion years of evolution as every other living thing. Amoebas continue to exist because they're very well adapted to life in each of the many different ecological niches they've colonised, from the bottom of the sea to the inside of your skull. ***LV***

HOW FAR BACK IN TIME WOULD WE BE ABLE TO GO AND STILL BREATHE OUR PLANET'S AIR?

Today, oxygen makes up roughly 21 per cent of our air, but it was virtually non-existent in Earth's early atmosphere. Soon after the advent of photosynthesis 2.4 billion years ago, oxygen levels crept up to one or two per cent – if you were to breathe this air, you would die almost immediately. Between 850 and 600 million years ago, oxygen concentrations increased steadily from two to about 10 per cent: still not enough for humans to survive on. Fast-forward to 400 million years ago and you could just about breathe but might feel dizzy and confused on about 16 per cent oxygen. Around 300 million years ago, oxygen levels reached a human-friendly 19 per cent and have not dropped below since. *AFC*

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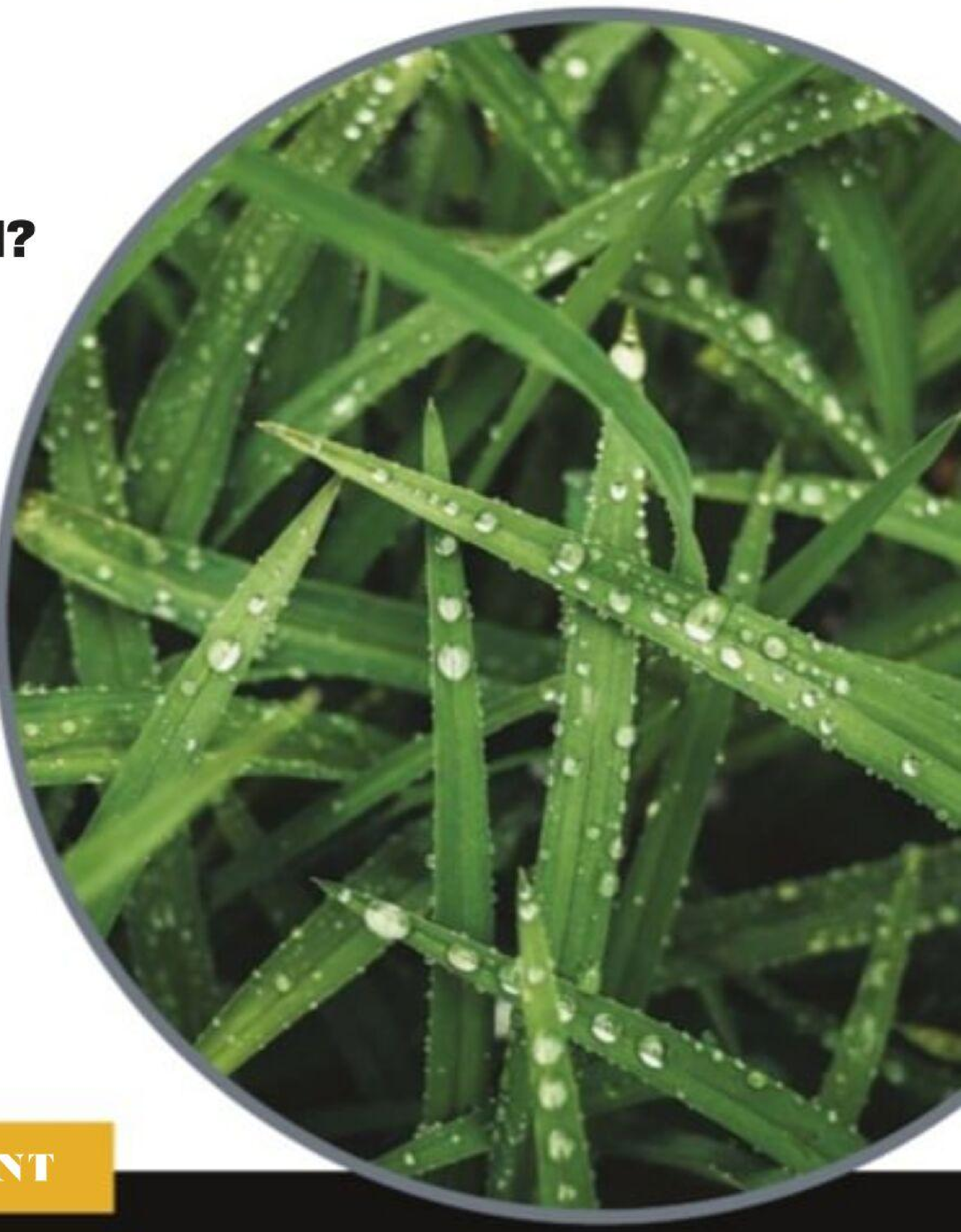
Why hasn't the amoeba evolved more? Because it doesn't need to…

WHY (AND HOW) DOES DEW FORM?



During the day, water evaporates from rivers and lakes, and plants pull it up through their roots and release it from their leaves. In the evening, the air cools and can't hold as much water vapour. The excess condenses into water droplets, which collects on any cold surfaces near the ground, where there is less wind. *LV*

THE THOUGHT EXPERIMENT

WHAT WOULD HAPPEN IF THE OCEAN FROZE OVER?

1. OIL PRICES SKYROCKET

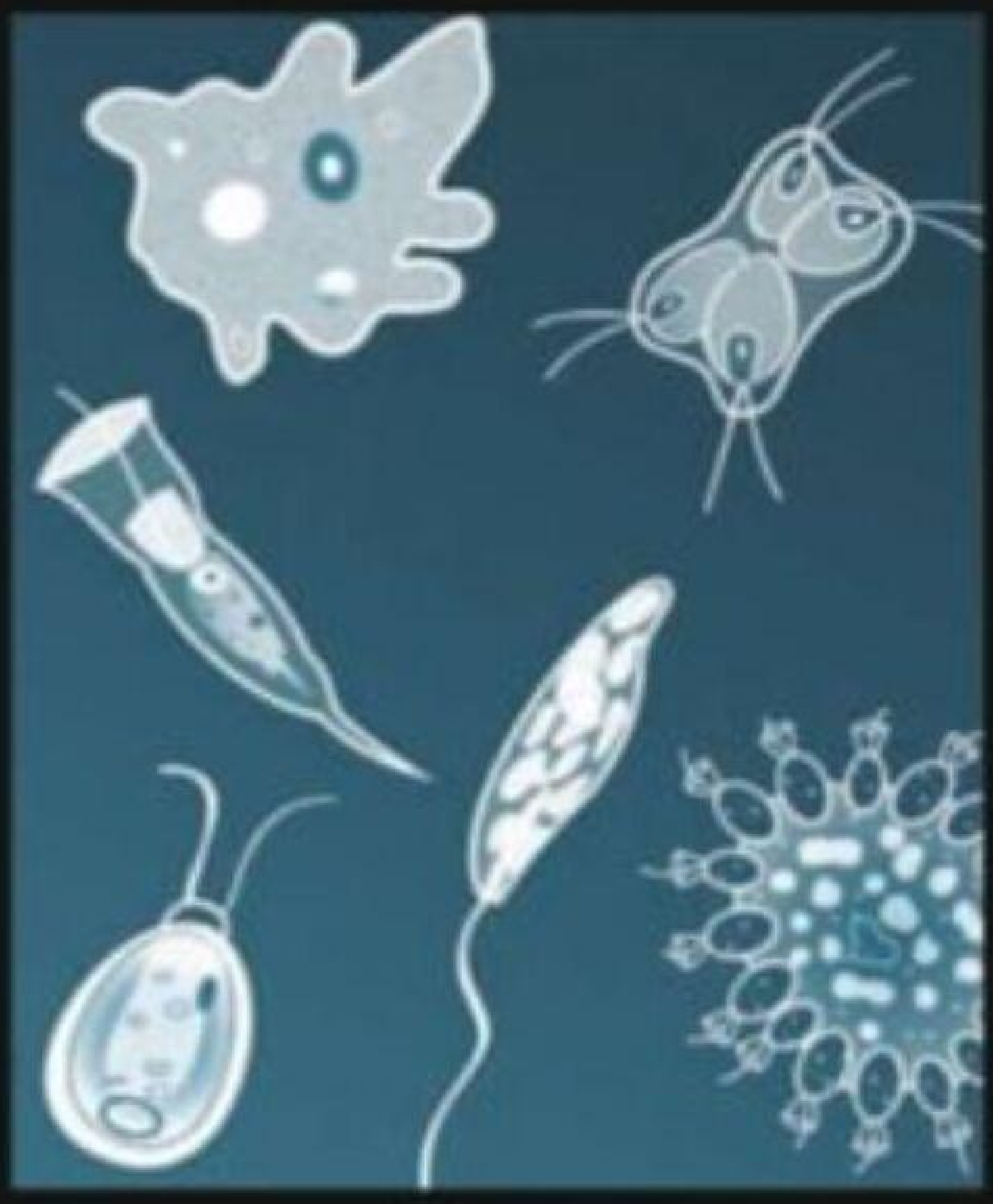
Half the world's oil is transported by sea. With the shipping lanes frozen over, the international oil market would be left facing a drastically restricted supply, just when oil is needed more than ever for heating. This would trigger global economic collapse, leading to martial law in many countries.

2. FOOD CHAIN COLLAPSE

The layer of ice over the oceans would block out most of the light getting to the surface water. This would kill off marine algae and the effects would ripple up the food chain until the oceans were almost sterile. Only deep-sea organisms living around hydrothermal vents would survive.

3. PLANTS DIE

Ice reflects more sunlight than water, so the global climate would cool drastically, freezing the land as well. Plants would die from lack of water, resulting in less CO_2 absorption, so CO_2 from volcanoes would slowly build up in the atmosphere and warm the planet back up – but it could take millions of years to thaw the ice.



4. IT'S HAPPENED BEFORE

Geological evidence suggests the oceans may have frozen at least twice before. The last time was around 650 million years ago. Enough single-celled organisms survived that event to repopulate the Earth, but the fossil record isn't good enough to tell if there were other, multicellular life forms that weren't so lucky.

WHICH IS BETTER FOR THE ENVIRONMENT: BURIAL OR CREMATION?

It takes 285kWh of gas and 15kWh of electricity to cremate a single person. The CO_2 this generates is roughly the same as an 800km car journey. But burial pollutes too. Formaldehyde used for embalming, and in the chipboard veneer used in 89 per cent of coffins, leaches into the groundwater. Concrete vaults also take a lot of energy to manufacture. The greenest option is currently to forego embalming of the corpse and opt for a woodland burial in a biodegradable cardboard or wicker coffin. ***LV***

Move to Singapore to stay safe and healthy, and enjoy spectacular views to boot

WHERE'S THE SAFEST PLACE ON EARTH TO LIVE?

The solitary confinement cells at the ADX Florence 'supermax' prison in Florida will keep you safe from most physical threats, including other prisoners. But your mental health will certainly suffer. If you want to live a more normal life while keeping safe, try Norway, which was ranked the safest country in 2018 by the Legatum Institute. To keep safe from disease, move to Singapore, which scored top for health and was still in third place for security. ***LV***

24.8m

Area in km^2 of the hole in the Antarctic ozone layer at its 2018 peak. The highest it has reached was 29.9m km^2 in September 2000

CAN TREES PREDICT THE WEATHER?

"Oak before ash, we'll have only a splash. Ash before oak, we're in for a soak." This saying claims that if oak trees come into leaf in spring before ash trees, then there will be less rain in the summer. Oak and ash trees do come into leaf at different times, because leaf growth in oaks is triggered by temperature, whereas ash trees use longer days as their signal. But there's no evidence that a warmer spring results in less rain that summer. Pine trees do close their cones in humid weather, though, which can indicate that rain is on its way. *LV*

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EYE OPENER

BEIJING, CHINA

What is this?

This isn't a close-up of some newly discovered spider, but a bird's-eye view of Beijing Daxing International Airport, currently under construction. The 'eyes' are skylights over the main hub of the terminal. The gates will be located along six spokes radiating from the centre, reducing the distance passengers have to walk: the maximum time to a gate should be eight minutes.

When it opens in September 2019, its four runways will serve 72 million passengers annually. A further three runways will be added later to bring that number to over 100 million, making it the world's busiest airport.

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THE EXPERTS

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Dr Emma Davies is a science writer who specialises in chemistry. She earned her PhD by studying the physical chemistry of ice cream

Prof Alice Gregory is a psychologist and sleep expert at Goldsmiths, University of London (@ProfAMGregory)

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Prof Robert Matthews is a physicist, a visiting professor at Aston University and *BBC Science Focus Magazine*'s science consultant

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Alexandra Franklin-Cheung is an environment and climate change expert based in London (@alexwlc)

Charlotte Corney is a conservationist, a trustee of the Wildheart Trust and former director of the Isle of Wight Zoo

Dr Alastair Gunn is a professional astrophysicist based at the Jodrell Bank Observatory and a fellow of the Royal Astronomical Society

Dr Helen Scales is a marine biologist, writer and broadcaster. Her latest book is *Eye of the Shoal* (@helenscales)

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If clouds can weigh tonnes, how do they stay aloft?

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How many hearts does an octopus have?

What would living on Mars do to my body?

Is it possible to sleep with your eyes open?

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Is it better to walk or run in the rain?

Why does light leave the position where it is created?

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